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WATER RESOURCES ACTIVITIES IN THE UNITED STATES. PRESENT AND PROSPECTIVE MEANS FOR IMPROVED REUSE OF WATER

Select Committee on National Water Resources, U. S. Senate

March 1960

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WATER RESOURCES ACTIVITIES IN THE UNITED STATES

PRESENT AND PROSPECTIVE MEANS FOR IMPROVED REUSE OF WATER

SELECT COMMITTEE ON NATIONAL WATER RESOURCES
UNITED STATES SENATE

PURSUANT TO

S. Res. 48

EIGHTY-SIXTH CONGRESS

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STATEMENT BY THE CHAIRMAN

MARCH 7, 1960.

To the Members of the Senate Select Committee on National Water Resources:

Senate Resolution 48 directs our committee to give attention to the character of legislation that may encourage the adoption of new technical methods and improved processes for increasing the usefulness of available water resources, including, among other possibilities, waste water salvage. As demands for water in the United States increase, it has become increasingly necessary for the public to use second hand water. With all indications pointing toward our present rate of water withdrawals increasing as much as threefold by 1980 and possibly by six times by the year 2000, the essentiality of improving our techniques for waste water salvage and reuse becomes apparent.

In order to secure necessary background information on this subject, the committee believed it was desirable to go beyond the services of the Federal agencies, which have undertaken most of the studies for the committee. We therefore made arrangements with Dr. Abel Wolman, professor of sanitary engineering at the Johns Hopkins University and an internationally known consulting engineer in the fields of pollution abatement, public health, and water supply, to prepare a report on present and prospective means for improved reuse of water in the United States.

The contract with Abel Wolman Associates, which was approved by our committee at a meeting held on August 18, 1959, and by the Rules Committee as of the same date, calls for a report to be prepared on technical means of improving water supplies and utilization in the United States by means of waste water salvage and other methods contemplated by, but not specifically referred to, in Senate Resolution 48. The report was to cover, but not necessarily be limited to, reuse of sewage effluent, underground storage of water, and improved methods of ground water discovery. The Wolman Associates were asked to appraise, insofar as practicable, the possible effects which the techniques covered would have on water supply costs, and to include discussion of geographical areas and environmental conditions to which they might potentially be suited, and to suggest any Federal or other action which might be helpful in the development of such techniques for use in the United States.

The excellent report which has been furnished the committee under this contract contains a comprehensive review of the water reuse practices now in use in this country and abroad. It indicates that 70 million of the 117 million people served by public water systems are reusing water that may have already passed through a domestic sewage or industrial waste disposal plant at least once, and that further concentration of population in urban centers, as our Nation grows, will tend to increase the percentage of reuse. The report is based on a review of several thousand technical papers and abstracts. It reviews present methods of reclaiming water from sewage and industrial wastes for reuse for domestic, industrial, and agricultural purposes, discusses the problems encountered in the reuse of water, and indicates the prospects for more intensive conservation of water supplies and utilization of waste waters. The report goes into considerable detail on the restoration and maintenance of underground water supplies, including ground water recharge as well as improved methods of locating and evaluating ground water supplies. Also, it covers methods of conservation, reclamation, and reuse of surface water supplies in industry and agriculture, as well as potentialities for control and reclamation of saline waters.

The report emphasizes that water reuse generally is dependent on the necessitics of local circumstances and that decisions as to reuse or reduction of use of water are, and will be determined by, economic factors. The point is made that comparisons of practice and management from one part of our country to another are rarely valid, unless corrected for the peculiar circumstances governing each situation.

As water becomes more and more scarce and the costs of development increase, the amount of water used per unit of output will be reduced, the ingenuity of water management will increase, and the improvement of our techniques will continue.

This report will be of great interest to you, to other Members of the Senate, and to all concerned with finding solutions to our future water problems, and therefore I am having it printed as one of our series of committee prints dealing with all aspects of water resource activities in the United States.

ROB'T S. KERR,
Chairman, Select Committee
on National Water Resources.

COMMUNICATIONS

THE JOHNS HOPKINS UNIVERSITY,
February 15, 1960.

Hon. ROBERT S. KERR,
Chairman, Select Committee on Natural Water Resources;
U.S. Senate, Washington, D.C.

MY DEAR SENATOR KERR: In compliance with your request of August 1959, we are submitting herewith a statement on present and prospective means for improved reuse of water. The document has been prepared in two parts: Part 1—which deals with the technical means of improving water supplies and utilization by means of waste water salvage and other methods and Part 2—which covers a reasonably complete bibliography of pertinent literature for permanent reference by interested workers.

We hope that the data here presented will reveal promising areas for future exploration and development, as needs arise.

Respectfully submitted.

ABEL WOLMAN
(For Abel Wolman Associates).

FOREWORD

The Senate Select Committee on National Water Resources has interested itself, among other aspects of water resources development, in "the technical means of improving water supplies and utilization in the United States by means of waste water salvage and other methods. * * *"

The report which follows is concerned with an elaboration of present and prospective means by which water resources may be progressively put to more effective management and use. Many of the procedures herein described have been the result of fortuitous decisions made necessary by local circumstance, geography and economic pressure.

It is axiomatic that water reuse generally follows upon the necessities of local circumstance. It is rarely practiced purely as a virtue and is unlikely to be militantly pursued unless the constellation of regulatory precepts, costs and private and public conscience and imagination warrants such action. The marketplace often determines decisions as to reuse or literal reduction of use.

Comparisons of practice and management from one part of our country to another are rarely valid, unless corrected for the peculiar circumstances governing each situation. For example, the amount of water used for each unit of any industrial product is determined by the availability and cost of water, the location of the industry, the nature of the receiving water, capacity for waste assimilation, etc. Where water is scarce, water management becomes more ingenious in use and reuse. Raising municipal water rates may decrease use and foster reuse—but not always.

At any rate, water utilization methods gain ascendancy as the gap between availability and demand increasingly closes. Such closures are not universally visible for the country as a whole. Examples are at hand, however, of wiser water management where water is hard to get, where competitive costs of alternative sources are rising, and where geographical juxtaposition is favorable for reuse. Aruba is illustrative of the first, southern California of the second, and Bethlehem Steel Co. use of treated sewage for industrial water a striking demonstration of the third.

The report, therefore, may serve well to summarize known and potential practices which may guide the user for the future. No small part of the document is devoted to a reuse of waters which is rarely considered as such, namely, the very wide use of surface bodies of water which have been the recipient of domestic and industrial wastes. These wastes, with much or little dilution and with much or little anterior treatment, have been reused with remarkably successful water treatment for a century or more. These practices are here included because they represent by far the greatest reuse of waters of which we have record.

The stimulation of reuse would not appear to require any significant additions to legislation, either on Federal or State levels. Perhaps more rapid progress in this form of water conservation may be initiated by greater recognition and stimulation of research and development by both private and public forces. Historically, such reuse as has occurred has been the result of both private and public initiative. It is under these auspices that progress will occur when the potentialities either become necessities, or research more actively pursued discloses favorable opportunities for the more economical use of water.

Research in water reuse cannot be overemphasized, because, both in private and public budget, money for research is so often less favored than money for construction and more obvious action programs.

The speed with which reuse comes into play will continue to be a result of marketplace pricing, in which new developments will have their impact.

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A REPORT UPON PRESENT AND PROSPECTIVE MEANS FOR IMPROVED REUSE OF WATER

(By Earnest F. Gloyna, Jerome B. Wolff, John C. Geyer, and Abel Wolman (Abel Wolman Associates), January 1960)

PART 1. TECHNICAL MEANS OF IMPROVING WATER SUPPLY AND UTILIZATION

General Considerations

The purpose of this report is to state in broad terms the present methods of reuse and conservation of water by domestic, industrial, and agricultural users; to outline the problems encountered in attempting effectively to reuse waste waters; and to indicate the prospects of more extensive conservation of water supplies and utilization of waste waters. These problems become important in the United States as competition for and cost of water for domestic, industrial, and agricultural uses increase in many areas. The rapid growth of population, together with the threat of overdraft of readily available supplies and their deterioration because of misuse and lack of control of manmade pollution, make it imperative that all possible avenues be explored to improve water conservation and reuse practices.

Three specific areas were studied in some detail; namely, the reuse of sewage and industrial waste waters, the restoration and maintenance of ground water supplies, and the reclamation and reuse of surface waters by industry and agriculture.

All responsible Federal, State, and local agencies recognize the need for the intelligent management and improvement of our water supplies. Since waste waters are a resource of great value, and promising methods of reclamation for reuse both of surface and underground supplies are at hand, it remains for a more concerted and better coordinated attack to be made on preventing, by private and public forces, the continuing deterioration of our water supplies.

Estimated Water Demands

With a population of nearly 180 million people in the United States, about 117 million are served with public water supplies. Of this number, 70 million are reusing water from sources which have already been used at least once for domestic sewage and industrial waste disposal. If the number of public water supply users reaches 150 million by 1975, the total consumption of water for domestic purposes may then be 30 billions of gallons per day. The population is concentrated in urbanized centers which discharge treated sewage into streams serving downstream communities. Further concentration of population in these urban centers will tend to increase the percentage of reuse of these receiving waters for municipal purposes.

The estimated domestic water demands of 30 billion gallons per day in 1975 are less than 7 percent of the total demands of 453 billion gallons daily for all purposes. However, the transmission and distribution of this water are frequently accomplished concomitantly with water supplied to commercial and industrial establishments in urban areas. Thus, water fit for human consumption frequently is the governing criterion in the reclamation and use of waste waters even though much of the water serves purposes for which a water of lower quality would be satisfactory.

Industry now uses nearly one-half of the 312 billions of gallons per day of water produced for public and private use, or 150 billion gallons daily. By 1975, industry may require as much as two-thirds of all of the water produced. The 1975 industrial demands have been variously estimated at from 250 to 400 billion gallons per day.

Approximately one-half of all of the water used by industry is required for process cooling water and boiler feed purposes. Only 2 percent of all of the water used by industry is actually consumed, with the greater portion returned to nature, and hence not actually lost. Only 1 percent of municipal waste waters is presently used by industry prior to return of these waters to natural streams.

Agriculture, which is second to industry in amount of usage, now consumes nearly 120 billion

gallons per day and is expected to need 170 billion gallons daily by 1975. Unlike industry, however, water use in agriculture is largely consumptive. That is, the greater portion of the water used, sometimes as much as 80 percent, is lost by transpiration and evaporation.

Only small amounts of waste waters are reused by agriculture, although, historically, one of the oldest methods of sewage disposal is land irrigation. Because of hygienic problems connected with the use of sewage effluent for agricultural purposes, sewage irrigated crops grown in the United States are used primarily for animal feed.

The growth in water use for all purposes in the United States between 1900 and 1960 is shown in table 1. It is clear that gross figures for total present or prospective water use, particularly when compared with the estimated potentially available amounts, must be used with caution. For the reason already stated, namely, the very large return of waste waters to natural watercourses, the gap between availability and need for 1975 is not as great as the gross figures would suggest.

TABLE 1.—*Estimated water use, 1900–60* [1]*—Average demand in billion gallons daily*

	Irrigation [2]	Public water supplies	Domestic [3]	Industrial and miscellaneous [4]	Steam electric power [5]	Total
1900	20.2	3.0	2.0	10.0	5.0	40.2
1910	30.6	4.7	2.2	14.0	6.5	68.4
1920	55.9	6.0	2.4	18.0	10.0	92.3
1930	60.2	8.0	2.9	21.0	18.4	110.5
1940	71.0	10.1	3.1	29.0	22.2	135.4
1950	100.0	14.1	4.6	46.0	38.4	204.1
1955	119.8	17.0	5.4	60.0	59.8	262.0
1960	135.0	22.0	6.0	71.9	77.6	312.5

[1] U.S. Department of Commerce, "Water Use in the United States, 1900–75," BSB–136, Washington, D.C. (January 1936).

[2] Total take, including delivery losses but not including reservoir evaporation. Approximately 80 percent of water delivered is consumed and not returned to watercourses.

[3] Nonfarm domestic use and farm domestic as well as farm stock wells. Approximately 10 percent of water delivered is consumed. Remainder is returned to watercourses.

[4] Manufacturing industry, mineral industry, commercial, air conditioning, resorts, motels, military, and miscellaneous. Approximately 2 percent of water delivered to industry is consumed. Remainder is returned to watercourses.

NATURAL WATER REUSE

Every community consumes water and produces domestic and industrial wastes. Where communities border large rivers or bodies of fresh water, they take water from these convenient sources and generally return domestic sewage and industrial wastes to the same waters. Thus along a river, each successive downstream community reuses a portion of flowing water time and again.

Although sewage treatment processes may remove considerable amounts of polluting substances from waste waters, depending on the efficiency of treatment, varying amounts of pollutants will, nevertheless, be returned to the receiving waters. The receiving waters, whether streams, lakes, seas, or oceans, have the capacity for self-purification by natural processes. These natural processes act more slowly than similar processes utilized in sewage treatment plants, but they accomplish the same purpose and ultimately result in the purification of the receiving waters.

The most complete and efficient types of sewage treatment utilized today do not of themselves produce water of a quality that is potable. The self-purification processes of the water into which the treated sewage effluents are discharged are essential to raise the quality of the water. In addition, further purification is necessary when the river water is withdrawn for use as a potable supply. Depending upon the degree of pollution of the water source, water purification processes including storage, disinfection, coagulation, sedimentation, and filtration are necessary to provide a safe potable water supply.

One important problem that has developed in connection with the growth of urban areas and the concentration of industry around these areas is that of the increasing concentration of complex chemicals from commercial and industrial operations. These chemical pollutants create a nuisance because of the inability of existing treatment processes to remove them effectively. They can cause unpleasant tastes and odors as well as highly alkaline or acid conditions, and some of them may prove to be harmful to humans.

As communities along water sources become more densely populated and intensely industrialized, high degrees of sewage treatment will be required to limit the amount of pollutants entering natural waters. With an estimated 40-percent increase in public water supply users by 1975, there will be an equal or greater percentage increase in the quantity of sewage and industrial wastes to be disposed of. To meet this situation, many additional treatment plants using improved methods for treating sewage will be required.

Among the new sewage and waste treatment processes being considered as supplemental means for obtaining higher quality of treated effluents are: Waste stabilization in oxidation ponds; microstraining (filtration to remove finely divided solids from the treated effluent); and coagulation followed by sand filtration. In addition, new combinations of conventional biological treatment processes will be used to obtain better effluents.

This section deals with natural water reuse by exploitation of polluted streams and other bodies of water. The use of such sources for water supply is universal in all countries of the world. This type of reuse is different from the direct reuse of sewage effluents from sewage treatment plants without benefit of the dilution in natural waters. Direct reuse is discussed in the next section of this report.

A. Domestic water supply from polluted surface sources

Many communities which are located near streams that receive large amounts of highly polluted waste waters from upstream communities and industries have no choice other than to utilize these streams. They must, therefore, depend heavily upon water purification processes to protect the quality of the municipal water.

Water purification.—Where industrial and domestic pollution of rivers and streams is great, purification is sometimes accomplished indirectly by causing the water to percolate through permeable sands and gravel to wells dug in the banks of the river. A considerable portion of the water taken from the Rhine and Ruhr Rivers in Germany is obtained in this manner. This practice is growing in the United States, and should receive increasing attention as a method of recovering usable water from polluted surface sources. It is dependent, however, upon the existence of appropriate geological formations and is not universally applicable.

The effectiveness of conventional water purification processes in rendering heavily polluted waters usable for human consumption is illustrated in two unusual cases which occurred at Ottumwa, Iowa, and Chanute, Kans.

At Chanute, Kans., a serious drought virtually dried up the Neosho River, the major source of supply other than a highly mineralized and meager ground water supply. Decision was made to use the domestic sewage effluent from the new biofiltration treatment plant, diluting it as much as possible with Neosho River water. During a period of several months the river water contained a substantial amount of sewage effluent. No ill effects were experienced by the population, although the water was of a poor chemical quality. Enteric viruses, found in the treated sewage, were not present after well-controlled water purification.

For 2 months the city of Ottumwa used treated river water containing one-third to one-half raw sewage effluent from the upstream city of Des Moines. By means of intensive water treatment, including heavy dosing of the effluent with chlorine, the treated water was rendered safe for human consumption.

The new combined trickling-filter activated-sludge installation in California at Squaw Valley, site of the 1960 winter Olympic games, is an example of intensive sewage treatment. The sewage plant effluent is discharged into the ground upstream from the well water supply. The treatment plant is located adjacent to the area housing the participants in the games. It was essential that the plant be esthetically pleasing and free from odor, that it be capable of accommodating "shock" loads—that is, sudden loads resulting from the sewage produced by 35,000 spectators at the games—and that the effluent be of the highest possible quality. The plant provides a combined sewage treatment method which includes both biological filtration and oxidation processes. Only one of these processes is usually utilized in standard sewage treatment plants. After this treatment, the effluent is chlorinated and discharged into an underground sand filter. This quadruple treatment is expected to achieve excellent results and should provide an exceptionally good effluent. The process is admittedly expensive, but it fits this specific requirement.[1]

Transmission of enteric diseases.—The basic problems affecting natural water reuse for domestic purposes relate to the transmission of disease organisms and the toxic effects of chemicals discharged into the waters. Although enteric organisms abound in sewage, modern sewage treatment can remove a large proportion of the disease-causing organisms. Water purification processes, when properly applied, can then produce a water which

[1] Waste Engineering, "Quadruple Sewage Treatment Designed for Olympic Ski Site," *31*, 22 (January 1960).

meets all modern bacteriological standards. Although there has been a growing concern with the recent incidence of enteric viral infections, recent studies have shown that despite the fact that these viruses are sometimes present in sewage and sewage effluents, no enteric virus disease other than infectious hepatitis has been shown to be waterborne.[2]

Synthetic detergents.—The growth in the use of synthetic detergents during the past 10 years has created some difficulty in both sewage and waste treatment processes. Most synthetic detergents eventually find their way into surface or ground waters. Concentrations of detergents in surface water supplies ranging from 3 to 3.5 parts per million have been extensively reported in the United States and abroad. In England, foam has been particularly troublesome in the River Lee. Dramatic foaming, interference with coagulation, taste, and odor production and turbidity in water supplies have been caused by synthetic detergents.[3]

The problem is serious because the surface-active ingredient of most detergents does not lend itself to biochemical degradation by sewage treatment processes. An obvious solution to this problem repeatedly suggested in the United States and Britain, is for detergent manufacturers to use materials less resistant to biochemical action. The prospect does not appear too bright because of the present large production of the resistant type surface-active agent, alkyl benzene sulfonate, commonly known as ABS. ABS production exceeded 455 million pounds in 1956.[4] A new type of ABS has been developed which is more susceptible to biochemical degradation. Recent tests show that while trickling filters removed only 67 percent of conventional ABS, they removed 94 percent of the new ABS.[5] Foam formation in the sewage effluent also was reduced with this new material.

The foregoing presents only a very brief description of sewage treatment plants and the possibilities for increasing efficiency of their performance. The subsequent purification and use of the effluents of these plants, after dilution in natural waters, provides one of the best examples of water reuse. This reuse is accomplished at remarkably low cost.

B. Industrial supply from polluted surface sources

Of the estimated 110 billion gallons daily of water used by industry in 1955, 101 billion gallons were taken from surface supplies. Of that amount, 83.0 billion gallons were fresh water and 18.0 billion gallons were from saline sources. This point is significant because it shows that industry is using vast amounts of fresh water and that ground water and saline water are at present a minor part of its supply.

Approximately one-half of the total industrial water supply in the Nation is used for cooling. When used for cooling on a "once through" basis and returned to the source, the water is changed but little. One deleterious effect of warming the water is that the higher temperatures may increase the rate of depletion of oxygen in the receiving streams. They may also promote the growth of blue-green algae which produce tastes and odors.

Methods of maintaining the quality of cooling waters are available to industry. They are described in greater detail in the section on "Conservation of Water Supplies in Industry."

Wastes from industry.—In some areas in the United States, industrial pollution or surface supplies renders them unusable for industrial as well as domestic supply. Although most industrial wastes are amenable to the same treatment processes as domestic sewage, certain substances such as grease and oil, hot liquids, gasoline and flammable solids, acids and poisonous chemicals cannot be eliminated by ordinary sewage treatment processes.[6]

The problem of increasing discharge of complex chemicals from industrial and commercial processes into surface waters and treatment facilities has been recognized by a number of regulatory agencies. For example, the Ohio River Valley Water Sanitation Commission recently reported that 61 of 100 municipal sewage treatment plants were experiencing difficulty in treating industrial wastes.[7] The deleterious effect of acid mine wastes on the Potomac and other rivers has been a matter of concern for many years.

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[2] Clark, N. A. and Chang, S. L., "Enteric Viruses in Water," J. AWWA, 51, 1313 (October 1959).

[3] Task group report, p. 2661 "Synthetic Detergents: Effects on Water Supplies," J. AWWA, 51, 1251, 1253 (October 1959),

[4] Ibid.

[5] "Second Progress Report of the Standing Technical Committee on Synthetic Detergents." Her Majesty's Stationery Office, London (1959).

[6] Imhoff, Karl, and Fair, Gordon M., "Sewage Treatment," Water-Borne Industrial Wastes, p. 248, John Wiley & Sons, New York (1956).

[7] Albertson, J. G., "Industries Should Handle Amenable Industrial Wastes," Wastes Engineering, 30, 742 (December 1959).

Since the volumes and strengths of wastes from industrial processes are extremely variable, the costs and sizes of facilities for treating these wastes vary greatly between industries. Whereas the smaller industries rely heavily upon existing municipal waste treatment facilities, the larger ones more frequently treat their own liquid wastes.

The American Cyanamid Co., which manufactures more than 800 chemical products at its Bound Brook plant in New Jersey, constructed its own plant capable of treating 17 million gallons of waste water per day. The West Virginia Pulp & Paper Co. in Luke, Md., has joined in a cooperative scheme for the construction of a 21-million-gallon-per-day capacity plant to treat pulpmill waste and sewage from three adjacent towns.

These are important examples of industry's recognition of its responsibility for handling its own waste products. There is a realization by some industrial users that in adding excess pollution to receiving waters they are in effect destroying a valuable natural resource. Since there is generally little opportunity for industry profitably to reclaim byproducts from wastes, it must accept the responsibility of returning its waste waters in a condition which will not be too deleterious to the receiving stream.

Recovery of byproducts.—Industry can and does reclaim from its wastes byproducts which are of economic value. This practice should be followed whenever the return will pay part of the cost of waste treatment.

Pulp and paper mills in the State of Washington are recovering sulfur dioxide, alcohol, and powdered lignins from their wastes. During the summer months, a considerable amount of waste liquor is sold as road binder and dust palliative. These reclamation practices are estimated to reduce the pollutional load by as much as 50 percent. A number of industries producing pulp, wool, leather, alcoholic liquors, and rubber have used simple screening to recover usable products contained in their waste waters. One of the early and successful byproducts from some pulp and paper mills is fine charcoal, used for many industrial filtration purposes.

The oil industry in the United States utilizes much of the salt water obtained from its drilling operations to repressurize the oil strata in order to increase the efficiency of oil recovery. In England, a dry-battery manufacturer recovers waste waters containing manganese and supplies these elements to agricultural users. The Emscher River Association in Germany has constructed special dephenolization plants at a number of its coke-oven works. Substantial income is obtained from the recovery and marketing of these phenols.

The hope that all industrial wastes represent potential "gold mines" of byproduct recovery and profit, however, is not supported by past experience. Often valuable materials may be recovered, but not at an economic profit.

Control of industrial wastes.—A number of successful approaches have been adopted to control industrial wastes. In nearly all instances, joint cooperation between regulatory agencies and the specific industry concerned is essential. The following methods or combinations of methods may be utilized in industrial pollution abatement: (1) the industry may provide its own waste-treatment facilities to remove the undesirable waste products before returning the effluent to the receiving waters; (2) the industry may provide sufficient pretreatment to permit discharge of the wastes to a municipal treatment plant; (3) the industry may contribute to the construction of additional municipal plant facilities in order that it be capable of handling their particular wastes.[8]

Pretreatment is essential where industrial wastes contain solids which may damage the sewerage system and pumping facilities. Pretreatment is also essential for highly alkaline or acid wastes. These wastes not only affect the efficiency of sewage treatment, but can, as in the case of acid mine or pickling wastes, render the receiving waters undesirable for further industrial or domestic use.

C. Effect of irrigation on surface water supplies

Agriculture is a major user of both surface and ground water supplies for irrigation. Irrigation, in turn, is a source of stream pollution. Although the practice of irrigation was developed in the arid regions, irrigation farming is increasing in the humid areas of the United States because of its demonstrated efficacy in increasing crop yields. The use of surface waters for irrigation, unlike industrial and domestic use, is largely consumptive; that is, about 80 percent of the water is lost to transpiration and evaporation.

[8] Ibid.

Salt concentration increase.—When water is used for irrigation, the dissolved salts from the soil are carried off with the drainage waters. Where the irrigation drainage flows back into surface waters, the salt concentration may be greatly increased. A striking example of the deterioration in quality of river water resulting from its use for irrigation is found along the Rio Grande River. The average burden of chlorides carried by the Rio Grande above El Paso, Tex., is about 48,000 tons per year. High rates of use for irrigation between El Paso and Fort Quitman greatly reduce the flow above Fort Quitman. In 1949, the annual chloride load carried by the river below Fort Quitman was 159,000 tons, over three times that above El Paso.

Chemical concentration increase.—An additional pollution problem arising from irrigation practices is the potential effect on river quality of spent irrigation water containing agricultural insecticides and herbicides. Approximately 12,000 tons of technical grade insecticides were applied to cotton in the six Eastern States during 1957.

The effect of the growing prevalence of irrigation practice throughout the United States must now be evaluated in terms of its impact on surface water quality. More extensive research should be undertaken on the quantitative as well as qualitative effect of addition of salts and other chemicals on surface waters, with particular reference to the potability of water.

D. Methods of controlling pollution of surface sources

No general solution to the problem of reducing pollution in surface waters is at hand. Aside from the highly industrialized and urbanized areas which may pollute large portions of a watershed, the problem is generally localized. In some areas of the country, pollution of surface waters is sufficiently severe to constitute an urgent regional problem which affects more than one State; in other areas it is primarily of local significance.

U.S. practice.—No national standards or regulations have been developed in the United States for the control of discharge of wastes into surface waters. However, water quality standards have been given thorough study by national technical organizations and agencies of the Federal Government. In some instances, interstate compacts have been drawn to establish standards of required treatment of polluted waters to render them usable for various uses. For example, an interstate compact between Connecticut, New York, and New Jersey has been successful in maintaining minimum standards of water quality in their tidal waters.

Between 1947 and 1955, seven States, Connecticut, Rhode Island, Massachusetts, Vermont, New York, New Hampshire, and Maine, joined in an interstate compact to coordinate a program of comprehensive river pollution control. Working through the individual State regulatory agencies, recommendations for improvements of stream conditions are made by the commission for individual river basins after complete studies of these basins are completed. Standards of water quality based upon expected river use are established, after which the individual States attempt to regulate river use to reach the established standards.

In Wisconsin, intense pollution has been caused on some rivers by the discharge of pulp and paper mill wastes. These industries and State agencies have cooperated in making river surveys to determine the effects of pollutional loads.

Because of the variability of conditions which cause pollution and the variation in the effect of pollution on receiving waters, there has been in the United States a substantial body of opinion holding that pollution should not be controlled by applying rigid standards on a statewide or regional basis. Rather, the solution of each problem should depend upon the water uses involved and the economics of abatement in each case. According to this philosophy, there should be a gain in values commensurate with the costs of control. On the other hand, there is a desire by others, particularly those charged with regulation of pollution on a local and State level, to develop uniform standards of waste water quality control. The principal argument in favor of this approach to the problem is that it is easier to obtain action when everybody is required to expend approximately the same amount of money on control measures regardless of local benefits to be gained.

Except in the case of interstate commissions established by compacts, control of surface water pollution and maintenance of water quality in the United States is undertaken by each State individually, sometimes without regard to the needs of adjacent States. Local authorities and munici-

palities receive guidance and direction from State agencies in the construction and operation of pollution control works. Construction of waste water collection and treatment facilities is ordinarily accomplished by local governmental agencies and by private industry.

Some States, particularly those with heavy population and industrial concentrations along streams, are providing financial aid to communities which do not have adequate funds to construct sewage treatment works. Industrial pollution is controlled by the industry concerned, usually in cooperation with the State board of health or pollution control agency.

Federal participation in local pollution control and abatement programs is not on a large scale, but is gradually increasing. The Federal Government now provides a small amount of matching funds to municipalities through State health departments where a need for pollution abatement is shown. This present program has been met with enthusiasm. It has stimulated the construction of a large number of treatment and collection works in municipalities of all sizes.

European practice.—The European approach to the water pollution problem has been somewhat different than that in the United States. It should be of interest, therefore, to examine certain European river and pollution control programs.

The United Kingdom and Western Germany have similar land areas and populations; each have approximately 100,000 square miles of land and populations of 50 millions. They both are highly industrialized and yet have a good deal of agriculture. Their similarity also extends to the fact that nearly all of their rivers have some degree of pollution, much of it caused by intensive industrial use.

In England, prior to 1948, local councils generally established and administered pollution abatement laws. Some regional authorities for the entire river basins were then in existence, such as the Thames Conservancy Board and the West Riding of Yorkshire River Board. Because of the better success of these control boards in maintaining standards over entire river basins, a River Boards Act was passed in 1948 to establish river authorities in England and Wales. There are more than 30 river boards in operation now. Their consent is required for discharge of wastes and they can regulate the quality and quantity of such discharges. They can resort to the courts for enforcement of their regulations. There is little information at present as to the success of the new organizations; there is every reason to hope that they are an improvement over the old local boards.

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Standards of quality for sewage effluent discharged into English rivers have been proposed by the Royal Commission on Sewage Disposal and have generally been adopted unofficially, but not legalized. The river boards are empowered to establish standards of quality for sewage effluents for entire rivers or portions of rivers. These boards have been instructed to base their standards on thorough surveys of the rivers, the variations of flow, the types of wastes discharged into them, and the expected use of the river waters.[9]

Germany, with its great industrial concentrations along the Rhine and its tributaries, has been concerned for many years with the widespread pollution caused by these industries. At present, river associations which control entire river basins are in operation. Notable among these river authorities are the Emschergenossenschaft, Ruhrverband, and the Niersverband. The river associations are unique in that they exercise very broad controls. They are responsible to the national government for maintaining these rivers in satisfactory conditions. They are not only regulatory, but are in effect large public works agencies having the power to design, construct, and operate river improvements, including sewage-treatment plants. The municipalities have the responsibility for constructing and maintaining the sewerage systems served by treatment plants. Revenues are obtained from sewer and water authorities, municipalities and private industry, through charges fixed by the river associations.

The river associations also carry on widespread research activities. They have been particularly active in investigating methods of improving sewage treatment processes.

Examination of the current trends in pollution control in England and Germany, as well as other European countries, shows that to a marked degree there is general agreement that the quality of surface waters should be maintained at a proper balance of interest between all of the users of the rivers. Thus, in Germany, certain rivers are

[9] Key, A., "A General Survey of Water Pollution in Europe," World Health Organization, Fourth European Seminar for Sanitary Engineers, pp. 1-94 (1956).

maintained for industrial purposes and cannot be used for potable supplies; other rivers must provide drinking water, and the river associations impose such measures as will maintain the higher quality of water required. The United Kingdom has adopted flexible standards to control the types of effluents discharged into their rivers, and such standards vary from river to river, depending upon its expected use.[10]

Direct Reuse of Domestic Sewage and Industrial Wastes

It was stated in the preceding section that higher degrees of water and waste treatment will be required as the population increases in this country. As the degree of the treatment of waste waters increases and as sources of natural water become more difficult to find or expensive to develop, the question arises as to whether or not it is or can be practicable to reutilize treated sewage effluent directly after treatment.

No simple answer can be given to this question. There are no cases of communities making direct reuse of treated sewage effluents for their potable water supplies. On the other hand, use of treated sewage effluents in industry is increasing. Few large users, however, have entered this field. Untreated as well as treated sewage is used for irrigation of crops, particularly in the arid regions of the world.

A. Domestic supply

Direct reuse of domestic sewage effluents for human consumption is not practiced without dilution with receiving waters prior to applying water purification processes. Reuse of sewage effluent for flush purposes for individual residences has been attempted on a very limited scale, and developmental work in this area has been undertaken by a number of manufacturers.

A study completed in 1958 by the National Research Council [11] on household aerobic sewage treatment systems showed that it may be practicable to conserve water by utilizing settled effluent from aerobic sewage treatment devices for flushing toilets. This would achieve recirculation of treated effluents from domestic waste treatment units and would require only a relatively small amount of makeup water.

The household aerobic sewerage system costs from $500 to $900 to construct and is from $200 to $600 higher in cost than the ordinary septic tank and tile disposal field installation which presently serves more than 17 million homes in the United States. The aerobic sewerage system is a self-contained household treatment device containing as a principal component an aeration tank having several hours detention time to provide aerobic biochemical stabilization. The degree of treatment resulting from this process compares favorably with that obtained in municipal treatment plants. Because the detention time is longer than in municipal treatment plants, the amount of sludge is greatly reduced. When this system is used to treat toilet wastes only, it may be incorporated in a closed system which uses the settled sewage effluent as a toilet flushing fluid.

Use of this type of system will probably be limited to situations where disposal of sewage effluent creates a health hazard, where there is lack of adequate percolation or space for underground disposal, or where water supply is limited or extremely costly. Current studies of this system lead to the conclusion that much additional research is needed on the problem of reuse of domestic wastes in individual homes. Among other things, a unit for individual household use should include a practical means for disinfecting or pasteurizing the recirculated water.[12]

B. Industrial water supply

Although present direct reuse of treated municipal waste waters by industry is small (estimated at 1 percent of total municipal wastes) existing examples of this practice demonstrate its great potential.

In Baltimore County, Md., the Bethlehem Steel Co. plant uses a total of 590 million gallons daily (m.g.d.) of cooling water. Most of this water is pumped from the Chesapeake Bay. However, because of its salinity, the bay water is unsuitable for cooling the hot rolling mills. Originally, the fresh water required was obtained from the ground but overdrafts of this source caused an increase in its salinity. The company then obtained the right to use the sewage effluent produced at the Back River treatment plant. Today, two pipelines, 60 and 96 inches in diameter, transport the entire sewage treatment plant output to the steel plant,

[10] Ibid.

[11] "Report on Individual Household Aerobic Sewage-Treated Systems," Publication No. 586, National Research Council (February 1958).

[12] Ibid.

where the effluent is chlorinated prior to use. Average demand for this effluent has increased from 20 m.g.d. in 1942 to 110 m.g.d. in 1960. Maximum demands have exceeded 130 m.g.d. and it is planned to utilize 150 m.g.d. by 1965.

Treated sewage effluents are frequently as good and sometimes of better quality than other raw water supplies. In the following example, the cost of developing a treated sewage supply was less than that of potable water. A petrochemical manufacturer in the Southwest undertook to determine on an economic basis the preferable source of its process water. The choice lay between a well water supply and a municipal sewage effluent. The municipality computed the amortized cost of an activated sludge process unit to be 60 cents per 1,000 gallons. The estimated cost of producing well water by the city was 63 cents per 1,000 gallons. The quality of the two waters, after softening treatment, were quite comparable. The industry chose the sewage effluent for its process water.

A method which helps to reduce the cost of reutilization of municipal sewage effluent is to construct the waste water reclamation plant at a convenient point on the sewer ahead of the central sewage treatment plant. Savings can be realized by eliminating all sludge handling and process facilities at the reclamation plant if the sludge can be sent by gravity to the central municipal plant. In two cases, at Azusa and Pomona, it was found that the cost of constructing a water reclamation plant upstream from the sewage treatment plant was 50 to 70 percent cheaper than the conventional method of providing complete sewage treatment facilities at the upstream plant.

The use of sewage effluents for industrial purposes in the United States is being accomplished in all areas where economics dictate its use. From an economic viewpoint, reclaimed municipal and industrial wastes have more value to industry than to any other prospective user. Municipal waste waters, though considerably degraded, are adequate for cooling and boiler feed waters. It is estimated that 50 percent of all industrial water is required for these uses. Because of the great difference in sewage effluent qualities, the requirements for industrial use and needed treatment for such use are highly variable.

In arid regions, municipal waste effluents are reused more than once. Copper plants at Hurley and Santa Rita, N. Mex., use municipal wastes for process makeup water and copper recovery. The Santa Rita copper plant uses septic tank effluent as process water and reclaims it a second time at its copper precipitating plant. Sewage is reused for boiler water at oil refining plants in Amarillo, Big Spring, and Odessa, Tex.

It is estimated that in 1975 Texas will produce 274 million gallons daily of domestic waste waters. This effluent will originate from the three-quarters of the State's population which is concentrated in the eastern third of the State. Based upon a conservative estimate of 25-percent reclamation of usable water from the sewage effluent, and on a current value of water of $133 per million gallons, the total value of this sewage would amount to $9,000 daily; or $3.3 million per year, if sale of the effluent could be made to nearby industries for cooling and process waters.

In the Los Angeles area, municipal wastes totaling approximately 465 million gallons daily are discharged into the Pacific Ocean. No fresh water source for dilution of the sewage effluent exists. It is estimated that 25 million gallons daily of these wastes may be amenable to industrial uses.[13]

Sewage effluents have been used for flooding underground formations to increase the recovery of oil. The practicality of this use is dependent entirely on economic considerations. Where it is cheaper to pump ground water or utilize other sources, these methods will be used. This is often the case because fields are not ordinarily located near populated communities.

European experience with domestic waste water for industrial reuse is similar to American practice. Sewage effluents from the Birmingham, Tame, and Rea District Board and from Stokes-on-Trent are used for power station condensers. Phosphate control is obtained by aeration of the sewage effluent and precipitation of phosphates in the presence of iron salts with 80 percent removal achieved. Conventional lime-soda softeners reduce hardness and further reduce phosphates to less than 1 part per million. Chlorine for disinfection and antifoam agents for counteracting detergents are used. The large Appleby-Froding-

[13] Hedger, H. E., and Rawn, A. M., "A Report Upon The Potential Reclamation of Sewage Now Wasting to the Ocean in Los Angeles County" (November 1958).

ham Steel Co. uses softened domestic sewage effluent as cooling water.

Costs of direct reuse of waste waters.—The conditions under which industry reclaims waste water vary greatly in different parts of the country. In some areas of the Southwest, industries reuse municipal waste waters because they represent the only available source. In other areas, where limited water supplies have made it necessary for industry to turn to alternative sources in order to grow and prosper, it has been found that it is sometimes cheaper to use municipal waste waters than other sources. In table 2, some examples of the costs of reusing municipal and industrial waste waters are compared with the costs of fresh water supplies.

C. Agricultural water supply

Irrigation with sewage.—The oldest method of sewage treatment is disposal on land. Land disposal of collected sewage was early recognized in Western Europe as an effective means of purifying sewage. Many European cities today, such as Bremen and Paris still operate disposal farms where sewage is spread on the ground with little or no pretreatment. In America, municipal sewage effluents are utilized for irrigation only in areas which have low annual rainfall.

TABLE 2.[1]—*Cost comparison, reused water versus alternate water in industry*

Location	Type of use	Quantity used per year, million gallons	Cost reused water, dollars per million gallons	Cost alternate water, dollars per million gallons
Grand Canyon, Ariz.	Powerplant	65	$370	[2] $2,000
Los Angeles, Calif.	Sewage plant	3,900	12	[4] 122
Baltimore, Md.	Steel plant	40,000	35	[3] 135
Amarillo, Tex.	Oil refinery	520	43	[5] 138
Big Spring, Tex.	do	720	49	175

[1] From table 8, Cost Data for Reclaimed Water Use, publication No. 12 "A Survey of Direct Utilization of Waste Waters," State Water Pollution Control Board, Sacramento, Calif.
[2] 1955 cost data.
[3] Effluent also used for irrigation.
[4] Only cost is pumping.
[5] 1959 cost data. Includes all operating costs and amortization of $5,000,000 investment.
[6] Does not include amortization. If added, would equal minimum city costs.

The terms "land disposal" or "land treatment" are used when disposal of sewage is the primary purpose of the operation and agricultural utilization is a secondary purpose. Sewage farming, on the other hand, refers to the practice of irrigating with treated sewage for the primary purpose of producing crops and animals.

In the United States, no sewage, regardless of the degree of treatment, is utilized in the irrigation of crops which are usually eaten raw. Even when the agricultural product is cooked before consumption, it is better practice not to apply sewage irrigation for a period of from 20 to 45 days before harvesting. A number of sewage borne organisms have been shown to be present on vegetables and fruits after ripening and marketing when sewage effluents are used for irrigation. Therefore, sanitary standards in the United States do not allow the use of raw sewage for truck farming.

On the other hand, when sewage treatment such as primary settling or disinfection is used, treated sewage effluents are considered safe for use on crops like cotton, beets, or vegetables grown for seed production. The use of sewage effluent for animal feed and pasture crops is general throughout the Western States. On table 3 are shown the types of treatments and crops grown with treated sewage effluents in the United States.

TABLE 3.—*Agricultural use of sewage effluent*

Location	Use
Arizona:	
Tucson	Cotton, grain, and pasture.
Grand Canyon	Lawn.
Miami	Park.
California:	
Bakersfield	Alfalfa, cattle, cotton, grasses, potatoes (pre-irrigation only).
Calaveros State Park	Trees.
Delano	Cattlefeed, cotton.
Fresno	Alfalfa, cattlefeed, corn, grain, grasses.
Hanford	Alfalfa, grasses, sorghum, sudan.
Mount Vernon Sanitary District.	Alfalfa, cattle, cotton, grain, grasses.
Ontario	Alfalfa, corn grain, grasses (dry), milk cows.
Orange County	Alfalfa, sugar beets, dry beans, dry peppers.
Pomona	Alfalfa, cattle, citrus, grain, grasses.
San Bernardino	Animal feed crops, orchards, berries.
San Francisco	Pastures, park lawns.
Taft	Cotton, Maize seed.
Tulare	Alfalfa, cattle, cotton, grain, grasses, sunflowers.
Visalia	Grain, walnuts, fruit.
Wasco	Alfalfa, maize seed, and cotton.
Texas, over 200 towns, including:	
Abilene	Cattle, grain, grasses, maize.
Kingsville	Alfalfa, corn, cotton, grain, grasses.
Lubbock	Barley, cotton, sorghum, wheat.
Midland	Cotton.
San Angelo	Animal feed crops.
San Antonio	Animal feed crops, lake for wildfowl.
Washington: Ephrata	Corn, hay.
Nevada: Las Vegas	Lawns.

In Germany, experiments show that potato tubers contained sewage-borne organisms 40 days after application of sewage; carrots were affected for 10 days; and cabbage leaves and certain berries had live organisms 5 days after application. When raw sewage containing typhoid-paratyphoid groups were sprayed on grasses, the wind carried

the spray a considerable distance and infected the grass for a period of 6 weeks. However, no pathogens were discovered on grass fertilized with stabilized sewage sludge. It is interesting to recall, however, that the Berlin sewage farms took care of all the Berlin sewage for growing crops for many years, without any public health detriment.

It was recently reported that only 125 municipal sewage treatment plants in the United States provide sewage effluent for agriculture.

The methods for agricultural use of sewage effluent include flooding, ridge and furrow, sprinkling or spraying, and broad-surface and sub-surface irrigation. The spray method, which has been very successful with industrial wastes from food processing plants, has been used extensively in Germany and more recently in the United States. The development of plastic and aluminum pipes has made it easy to move the irrigation equipment from one field to another.

The European practice of ridge and furrow irrigation is usually restricted to vegetable crops. The vegetables are grown on a ridge about 1 foot above the furrows, which are spaced several feet apart. In Germany the city of Leipzig distributes sewage effluent to 57,000 acres of irrigated land by this scheme.

Flood irrigation is accomplished by flooding level fields on which dikes have been erected to prevent the loss of irrigation waters. The ground is alternately flooded by sewage effluent and rested. This method may be combined with other systems. Melbourne, Australia, transports its wastes 20 miles to irrigate a total of 14,000 acres by flood irrigation. This sewage is not pretreated except for lagooning.

In the cities of Upland and Ontario, Calif., a secondary treated sewage effluent is utilized for irrigation, with a combination of flooding, furrows, and sprinkling.

Subsurface irrigation has received considerable attention in Germany. By use of a special perforated pipe, sewage effluent can be distributed throughout the irrigated areas uniformly. It is claimed that this system enhances the yield by providing more thorough penetration of water to the root structures of the vegetables.

As was stated earlier, in the United States the practice of irrigation with municipal sewage effluents has been limited to the arid and semiarid West. Generally, sewage effluents, with or without treatment, can be used successfully wherever conventional irrigation can be practiced with surface and ground waters. The use of sewage effluent for growing grains, cotton, hay, and grass has many advantages. Reclaimed sewage supplements the limited water supplies and adds nutrients to the land. Sewage irrigation, well controlled, may eliminate the possibility of stream pollution.

Israel is an outstanding example of a country which must utilize all possible water sources. Of the anticipated need for 400 billion gallons per year required for irrigation, sewage effluent is expected to supply at least 10 percent. This is equivalent to sufficient water to irrigate 50,000 acres. Because of the tremendous value of water supply to agriculture in Israel, a project is now underway which will allow the transport of sewage effluent from Tel Aviv to the Negev, 60 miles away. Not only is water needed, but the nutrients in the effluent are the important constituents sought. Municipal sewage may be used in Israel simultaneously to grow feed crops, stabilize shifting sands, and to raise the water table. An important secondary effect of the raising of the water table is control of salt water intrusion.

Use of sludge for fertilizer.—In England where, because of high concentration of population and inadequacy of land area, land disposal and sewage farming has generally been displaced by the use of treatment plants and river or sea disposal, there is a great deal of interest in the use of sludge sewage for agricultural purposes. The dry weight of solids recovered from sewage plants in Wales and England is about 800,000 tons per year. The 350,000 tons which is applied to the land supplies 10,000 tons of nitrogen, 5,000 tons of phosphorus, and 12,000 tons of potassium.

The city of San Diego recently undertook an investigation of the practicability and economics of applying liquid digested sludge from their primary treatment plant to wastelands owned by them. The scheme was investigated as an alternative to their former practice of preparing a completely packaged fertilizer from digested sludge. It was found that not only could a savings of $16 per ton of dry solids be realized from the use of liquid digested sludge on the wasteland but comparatively low sludge loadings would produce

crop growth comparable to the growth achieved with the use of commercial fertilizers.[14]

Irrigation with industrial wastes.—Some food-processing industries in the United States have found it practicable to dispose of their wastes by irrigation. Food processers found that lagooning and ridge and furrow methods of irrigation were unsatisfactory because of odor problems and the need for constant attendance to prevent ponding in ditches. This led to the use of spray irrigation. Spray irrigation of these wastes was first reported in 1947 and in 5 years more than 40 plants were using this form of effluent disposal.[15] Experiments showed that whey and other wastes from cheese factories could be used successfully for plants such as grasses, clover, and lucerne. Better results were found with sandy than with loamy soils.[16]

In Germany, agricultural use of milk waste waters appears the most practicable method of disposal. Discharge of these wastes into fishponds has also given satisfactory results.[17] Since 1924 potato flour wastes have been utilized for agricultural purposes by spraying in Holland. Waste waters from sugar production in a sugar beet factory in Euskirchen, Germany, are disposed of, after sedimentation and sludge removal, by spreading over grassland with good results.[18]

The irrigation of woodlands offers a promising use for sewage and industrial waste effluents. In Bridgeton, N.J., the problem of disposing of 10 million gallons per day of vegetable processing waste water was solved with highly satisfactory results by disposing of the waste waters, after primary treatment and chlorination, by spraying a 180-acre tract of woodland containing oak trees and a ground cover of dogwood and mountain laurel. The project was undertaken after a study was made of the costs involved in disposing of the plant effluent either by high rate filtration or by spraying the effluent in the wooded area. Cost of the high rate filter treatment plant was estimated at $1.75 million as against an actual cost of $150,000 for the adopted method of disposal of the effluent by spraying. The rate of application has ranged from 500 to 600 inches per year over an 8-month period. Peak application rates of 1,200 inches per year have been experienced. During the irrigation season ground water levels have increased as much as 22 feet.[19]

Lush growth in the wooded area occurred as a result of the spraying. There was no evidence of soil clogging. Ground water levels were raised, and the quality of water taken from wells in the area was excellent. This project recharged the ground from which the water used in processing operations had been taken.

The successful experience in New Jersey with the irrigation of forest lands is not unique. In England a species of willow was irrigated with sewage. Because of the demonstrated ability of woodlands to transpire and assimilate large quantities of water, their value in disposal of sewage effluents should be investigated further.[20]

Costs of reuse of sewage effluents in agriculture.—In table 4 a comparison between costs of reusing sewage effluents and the use of alternate water supplies for agricultural purposes is given. Although there is some question as to whether the sale of sewage effluent will ever become a widespread practice because of the relatively high value of land near urbanized centers, it is quite economical where isolated communities are near large

TABLE 4.[1]—*Cost comparison,*[2] *reused water versus alternate water in agriculture*

Location	Type of use	Quantity used (acre-feet per year)	Cost, reused water (dollars per acre-foot)	Cost, alternate water (dollars per acre-foot)
Pomona, Calif.	Irrigation	2,200	6–7.50	[3] 20
San Bernardino, Calif.	do	5,000	31	[4] 10
San Francisco, Calif.	Park, lakes	700	23.00	70
Taft, Calif.	Irrigation	250	6.00	[5]
Talbert, Calif.	do	2,800	6.00	[5]
Abilene, Tex.	do	5,500	[7]	[8] 80
Kingsville, Tex.	do	1,100	[7]	[9] [9] 65
San Antonio, Tex.	do	2,600	[7]	[9] [10] 25

[1] From table 8, Cost Data for Reclaimed Water Use, Publication No. 12, "A Survey of Direct Utilization of Waste Waters," State water pollution board, Sacramento, Calif.
[2] 1955 cost data. Costs are shown as dollars per acre-foot.
[3] Effluent is sold to 2 water users.
[4] Effluent is sold to a water company.
[5] No alternate water available.
[6] Alternate water unsatisfactory.
[7] No cost.
[8] Cost shown is municipal water cost.
[9] Effluent free in return for furnishing plant site.
[10] Effluent free in return for granting city easement on 700 acres.

[14] Merz, R. C., "Utilization of Liquid Sludge," Water and Sewage Works, 106, 489 (November 1959).
[15] Sanborn, N.H., "Disposal of Food Processing Wastes by Spray Irrigation," Sewage and Industrial Wastes, 25, 1034 (September 1953).
[16] Schropp, W., "Experiments Concerning the Influence of Dairy Waste Waters on the Development of Plants," International Dairy Congress (1953) 3, 966–969: Dairy SCI. ABS, 15, 703 (1953).
[17] Hess, F., and Meer, F., "Treatment of Milk Trade Waste Waters," Wass, U. Boden (1952), 4, No. 1: Ost. Wasserw., 4, 299 (1952).
[18] Falkenhain, H. S., "Treatment of Waste Waters From the Sugar Factory of Euskirchen," Zuker (1957) 389–390: Chem. Zbl, 123, 1222 (1952).
[19] Webster, R. A., Discussion, "Sewage Effluent Disposal Through Crop Irrigation," Sewage and Industrial Wastes, 26, 133 (February 1954).
[20] Merz, R. C., et al., "A Survey of Direct Utilization of Waste Waters," State Water Pollution Control Board, California (1955).

areas of low-cost land. In the Southwest, lands high in alkalis are particularly well suited for reclamation with the use of sewage effluents. The use of irrigation for the disposal of wastes from food-processing industries appears particularly promising. This is especially true where these plants are remote from population centers.

The data in table 4 show that there are advantages to be gained from the reuse of sewage and industrial process wastes in agriculture; particularly in semiarid areas where agricultural water is difficult, and at times, impossible, to get. However, the position of agriculture in the water economy of this Nation should be viewed in its proper perspective when the question of competition of irrigation with industrial water needs arises. While municipal and industrial uses of water are largely nonconsumptive (90 percent and 98 percent, respectively, of the water used is returned to its source or discharged elsewhere), agriculture consumes, without return, more than 80 percent of the water used. For this reason, the use of water for irrigation may, in many situations, be less profitable than the use of water for industrial operations.

While 1,000 gallons of water can produce about 10 cents worth of crops, manufactured goods worth $11.70 can be made using the same 1,000 gallons of water.[21] Thus, in many arid and semiarid areas, development of water resources or their continued use for irrigation may no longer constitute the best use of water.

Underground Storage of Water

Because of its relatively constant temperature, its uniform and frequently satisfactory quality, its local availability, and its comparative cheapness, ground water is an important source of water supply throughout the world. Ground water supplies are taken from three principal sources: (1) the glacial, alluvial, or windblown deposits of granular materials such as sand, gravel, and sandstone; (2) from the solution passages, caverns, or fractures of rock; and (3) from combinations of these consolidated and unconsolidated geological formations.[22]

Water reaches these formations, called aquifers, by downward percolation of rain and other surface waters. Ground water exists in natural underground reservoirs, which, in parts of this country, are being drawn on at a faster rate than they can be replenished. Municipal and private ground water supplies, though smaller in daily delivery, are much more numerous than surface water supplies.

Use of ground water for irrigation, and by industries, municipalities, and rural homes has increased from 20 billion gallons daily in 1935, to 46 billion gallons daily in 1955. The ground water demands for 1975 have been estimated at 69 billion gallons per day. Ground water supplied about 19 percent of the total demand of 240 billion gallons per day and 28 percent of the demand of 17 billion gallons daily for public supplies in the United States in 1955.[23] Thus, it is an important resource upon which a large segment of the population depends. Ground water usage varies widely from State to State. In 1955, South Dakota obtained 76 percent of its total water demands from the ground, while the two greatest users of ground water, California and Texas, took 36 percent and 48 percent, respectively, of their total supplies from ground water.

Some areas in the West and Southwest have seriously depleted their ground water reservoirs. Typical of those ground water reservoirs where replenishment is much less than the rate of withdrawal are: Santa Cruz Valley of the Gila River in Arizona; Antelope Valley, Calif.; and Mimbres Valley, N. Mex.

The Southern High Plains area of Texas and New Mexico has a great amount of water stored in its underground reservoirs but the rate of withdrawal has increased prodigiously in the past decade. The amount of natural recharge is estimated at only 4 percent of the estimated withdrawal. As a result, in the areas of concentrated drafts the water tables have decreased greatly—for example, as much as 40 feet near Lubbock and Plainview. It is estimated that the total storage of underground water is in excess of 150 million acre-feet, two-thirds of which is within 200 feet of the land surface.

This underground storage would be adequate for decades if the well locations were distributed over the aquifer in a planned manner.[24]

[21] Powell, S. T., "Relative Economic Returns from Industrial and Agricultural Water Uses," J. AWWA, 48, 991 (August 1956).

[22] Fair, G. M., and Geyer, J. C., "Water Supply and Waste-Water Disposal," p. 37, John Wiley & Sons, Inc., New York (1954).

[23] MacKichan, K. A., "Estimated Use of Water in the United States, 1955," J. AWWA, 48, 369-391 (April 1957).

[24] Thomas, Harold E., "The Conservation of Ground Water," p. 37, McGraw-Hill, Inc., (1951).

In some cases the effect of overdraft has resulted in much greater costs of exploiting the ground-water source. Ground-water users have been obliged to drill deeper into the earth to find new supplies as the ground-water levels have fallen, and in addition have had to purchase more expensive well equipment. Finally, they are faced with a higher operating cost to lift the water to the surface.

In Santa Clara, Calif., where farmers formerly obtained ample ground-water supplies at 8 feet, they now are drilling more than 200 feet to reach ground water. In the Mendota-Huron area west of Fresno the annual decline in the water table has averaged from 4 to 30 feet. By 1955, the water table had fallen to a maximum of 300 feet below the surface. The net overdraft in this area exceeded 740,000 acre-feet in 1953.[25]

In California it is estimated that the total overdraft on ground-water supplies is in excess of 2 million acre-feet annually.[26] A well-known example of overdraft of ground-water supplies exists in the west coast basin where water which once overflowed in artesian springs is now as much as 15 feet below sea level. Intrusion of sea water, which has accompanied this decline of water table in the Los Angeles area, threatens the usefulness of the entire underground storage area.

The largest single use of ground water in the United States is for irrigation. In 1955, 30 billion gallons per day of ground water were used for irrigation. This amounted to 65 percent of the total of 46 billion gallons daily production of ground water. Of the total ground-water usage, 91 percent was pumped in 17 Western States, where arid conditions have fostered extensive development of irrigation.

The use of ground water for spray irrigation of crops in the relatively humid Eastern States has been expanding since World War II. How great this demand may be in the future is uncertain. Some agriculturists have predicted large growths in supplemental irrigation in humid areas.[27]

The introduction of the vertical pump having better efficiencies and capable of pumping from greater depths, the decreasing cost of electricity, and the use of improved internal combustion engines have all contributed to the increasing use of ground water. That these advances stimulated the increase in ground water usage is well illustrated in the high plains of Texas where the number of wells multiplied 25 times from 2,000 in 1940, to 50,000 in 1957.

A. Ground-water recharge

Because of the rapidly falling ground-water levels, much attention has been centered on the use of ground-water recharge for restoring ground water supplies. Reclaimable waters potentially useful for artificial recharge are flood waters, industrial wastes, and domestic sewage. These waters can be discharged into ground water either by spreading on the ground surface or by pumping underground.

A study made in 1955 showed that a total of 700 million gallons per day were being artificially recharged into the ground. This represents only 1.5 percent of the total withdrawals of ground water in the United States. On table 5 the sources from which artificial recharge water is taken are shown.

TABLE 5.[1]—*Summary of known artificial recharge in the United States in 1955*

[Quantities in million gallons per day]

Air conditioning return	41
Industrial wastes	47
Surface waters	540
Public water supplies	71
Total	700

[1] From table 13, "Estimated Use of Water in the United States," by MacKichan, K. A., J. AWWA, 49, 389 (April 1957).

Advantages to be gained from ground-water recharge are numerous. Ground water supplies can be replenished where overdrafts have endangered municipal water supplies; the quality of the liquid applied can be improved as a result of the filtering effect of the soil and aquifers through which the liquid flows; the water is less subject to contamination by poisonous materials or radioactivity in the event of war; loss of the ground water from sea water intrusion can be stopped; and excess surface waters from floods can be utilized to replenish ground-water reservoirs.

Methods of accomplishing artificial ground water recharge are (1) surface spreading and (2) injection by means of wells. The surface spreading method of recharge is used when previous materials exist between the ground surface and the

[25] Ibid.

[26] Studies in Water Reclamation, Technical Bulletin No. 13, Sanitary Engineering Research Laboratory, University of California, p. 5 (July 1955).

[27] Davis, John R., "Future of Irrigation in Humid Areas," J. AWWA, 48, 982 (August 1956).

aquifer and sufficient land area is available on which to carry out this operation.

B. Surface spreading

Artificial recharge of ground water reservoirs by spreading techniques has been successfully carried on in Europe and the United States for many years. The earliest known surface spreading project in the United States was initiated in Denver, Colo., in 1889.

Surface spreading is accomplished by directing the water into charging ditches or basins or by flooding suitable areas above the ground water basin. Water from streams, rivers and lakes, or cooling waters from industrial operations or treated sewage effluents are introduced into the spreading area. These waters leach into the ground to increase the natural ground-water supplies.

It is the practice in both this country and in Europe to use untreated surface waters for recharging depleted ground-water reservoirs. The costs can vary greatly. It is estimated that recharge costs range from $2 to $8 per acre-foot, depending upon the cost of the land.

Effective recharge by storm water has been accomplished on Long Island, N.Y. There are more than 300 recharge basins under the control of Nassau County. Many others are under the control of State and city authorities. Storm sewers direct the water to basins from which substantial amounts percolate to the aquifer. The plan not only saves water but also reduces storm drain costs. One of the largest recharge basins drains an area of more than three square miles. It has a capacity of 3.7 million cubic feet and is 11 feet deep. The average rate of recharge for this basin, using depths of water varying from 0.5 to 9 feet, is about 23 gallons per square foot per day. This is equivalent to a recharge of 8 million gallons per day. The usual design rate for recharge basins in Long Island is 11 gallons per square foot per day.

The city of Bountiful, Utah, recharged the ground by damming two creeks so that excess flows would discharge into canals and over permeable brushland. Approximately 420 acre-feet or 137 million gallons per year have been returned to ground water, and the water table has risen 15 feet.

Well-designed spreading basins are operated along the Ruhr Valley in Germany. Some of these basins measure 1,300 feet in length and 100 feet in width, with a depth of 10 feet. It is believed that spreading basins have contributed more to ground water recharge in the Ruhr Valley than has natural river bank infiltration.

Surface spreading is also practiced in Sweden, Belgium and the Netherlands. In the Netherlands widespread surface spreading of treated surface water is accomplished to supply Amsterdam, The Hague and other cities. Originally, ground water supplies of excellent quality were drawn from sand dunes. As a result of overdraft, sea water intrusion occurred and in some places high salinities were experienced. Polluted Rhine River water is diverted to these dunes, and after prefiltration the river water is spread into the dune sands. The results of these spreading operations have been good.[28]

Surface spreading by basins has been utilized extensively in the vicinity of Perth Amboy, Princeton, Lake Mohawk, Seabrook, and East Orange, N.J.

The greatest use of artificial recharge by surface spreading has been in the State of California. Between 1941 and 1954, approximately 2 million acre-feet of water was artificially placed in ground water reservoirs. Most of the spreading operations are located in the Santa Clara Valley, south of San Joaquin Valley, and in southern California. In 1954, there were over 1,800 acres of spreading areas under the control of the Los Angeles Flood Control District. Of the total estimated recharge of 700 million gallons per day in 1955, California contributed 435 million gallons per day, or in excess of 62 percent of the total.[29]

C. Recharge wells

Recharge wells are generally used only where spreading cannot be employed. The use of wells to recharge with surface waters has been only moderately successful because where the water is poor in quality, clogging of the areas adjacent to the well casings soon renders the wells inoperative. However, there are some notable examples of successful recharge of ground water supplies by wells. As techniques are improved it is likely that their use will increase.

[28] Krul, W. F. J. M., "Actual Trends in Sanitary Engineering and Water Supply in Europe," J. NEWWA, 72, 175-176 (June 1958).

[29] MacKichan, K. A., "Estimated Use of Water in the United States, 1955," J. AWWA, 48, 369-391 (April 1957).

Tests made in California indicate that from 0.4 to 2 cubic feet per second having more than 15 parts per million of chlorine may be injected continuously for a month before redevelopment of the well is necessary. Closed-circuit well injection of ground water used for cooling in industry gives satisfactory results without treatment.

It is estimated that costs of well recharge, including installation, redevelopment, treatment, and injection, range from $15 to $25 per acre-foot of injected water. This is a high cost in comparison with the cost of artificial recharge by surface spreading. Hence, this method is used principally where the value of water is high or where secondary purposes may be served.

An example of dual purposes for recharging is the injection of fresh water into wells in California and Long Island, New York to prevent simultaneously sea water intrusion resulting from overdrafts of the ground water supply, and to restore ground water levels. At Manhattan Beach, Calif., treated Colorado River water was injected into nine 12-inch diameter wells spaced at 500-foot intervals by applying heads of 40 to 50 feet to the wells. Tests indicated that chlorination was necessary in order to prevent clogging of the pores by otherwise harmless organisms. A total injection rate of 4.5 cubic feet per second of treated water was sustained. Because of the importance of this project to the area, consideration is being given to the formation of a water replenishment district to make certain that an adequate supply is available to maintain a continuous barrier against salt water intrusion.

On Long Island, starting in 1933, sea water encroachment was reduced by the requirement that persons who pump in excess of 59.4 gallons per minute from wells for cooling and air conditioning must return the used water to the ground in an uncontaminated condition. More than 1,100 recharge wells have been drilled on Long Island since 1933. Experience has shown that gravel filters between an inner and outer casing are desirable. When given proper maintenance, some of the recharge wells have operated for more than 20 years at recharge rates varying from 0.2 to 0.5 cubic feet per second. Temperatures of recharged water are from 2 to 20° F. higher than the water taken from the ground. Although the temperature of ground water has been increased, this effect appears to be localized to the areas where concentrated recharges occur. Increases in the temperature of ground water are noted where cooling water is recharged by wells in Sacramento, Calif. Some well water temperatures have risen as much as 20° F.

Wells producing brackish water have been successfully recharged with fresh water in El Paso, Tex.; Camp Peary, Va.; and Brooklyn, N.Y. There appears to be little intermixture of the fresh and saline waters. The experience at these locations indicates that aquifers containing highly mineralized waters can be used successfully for storage of fresh waters.

D. Intermittent recharge

Advantages can accrue from the intermittent use of recharge basins and recharge wells to fit varying water demands as well as to provide cool water for industrial purposes. Two excellent examples of this practice are cited below.

A recharge project in Peoria, Ill., was undertaken in 1951 for the dual purpose of studying recharge by spreading and for augmenting the well supplies for industry and water utilities. In this case the river water used was chlorinated before it was introduced into the spreading basin. The recharge operations are carried on only during the cooler 6 months of the year when river water temperature is below 60° C. in order to maintain water temperature in the ground water at the lowest practicable level.

Another example of the use of intermittent recharge is the Louisville, Ky., operation, which is accomplished by recharging existing wells. Here the aquifer was being pumped by industries needing cool water at a rate of 20 million gallons per day in excess of natural recharge. In 1944, the ground water levels were dangerously low. During cool weather, pumpage was reduced, conservation practiced, and purified city water used to recharge the production wells. A total of 1.7 million gallons per day of cold city water was returned to the ground reservoir. This recharge, in addition to natural recharge, has resulted in an adequate supply of cool water during summer months when city water is too warm for industrial needs.

Storing of cool water in aquifers during the offpeak season for later use during maximum demand periods has been used successfully in Lubbock, Tex., and Binghamton, N.Y. Re-

charge operations of this kind may be practical and desirable in many other parts of the country to meet the growing problem of supplying demands for water during summer peaks.

Artificial recharge experiments at Amarillo, Tex., to determine the practicability of storing water in natural underground reservoirs by injection wells to meet peak demands during summer months were recently completed. The results of this investigation should be useful in many other areas. Water was injected into the underground formation during winter months at a rate of 1,000 gallons per minute. It was possible to recover 80 percent of the injected recharge water during the remainder of the year. Substantial savings may be realized as a result of this work. The rapid growth of the city made it necessary to consider the use of conventional reservoirs to meet maximum demands. Development of storage in the vicinity of the existing city water supply well field will make it possible to construct smaller supply lines to new, distant well fields or surface sources. Lower pumping rates will also be possible. Cost of the proposed storage will be the only outlay for the recharge wells.[30]

E. Recharge with sewage effluents

The practice of recharge of ground waters by surface spreading either floodwaters or fresh waters long antedates the spreading of sewage plant effluents. One of the first studies of spreading of treated sewage was undertaken in Los Angeles, Calif., in 1930. These studies showed that a highly treated sewage could be safely applied to the ground water by spreading. Nevertheless the method was not widely adopted. In 1942, a committee of the American Society of Civil Engineers found that planned waste water reclamation by ground water recharge was both rare and uneconomical.[31]

In 1949 further study showed that it was both economical and technically feasible to recharge the ground with treated sewage and industrial wastes. Experimental spreading basins were established in Whittier and Azusa by the Los Angeles County Flood Control District. The sewage was treated in biofiltration plants and received secondary treatment prior to spreading. These tests demonstrated that there was no significant bacterial contamination below a depth of 7 to 10 feet and there was no significant contamination of ground water. These experiments also showed conclusively that an organic mat of increasing ability to filter out bacteria forms at the soil surface and substantially reduces bacteria in the infiltrating waters.

A 3-year study of the technical feasibility and possible effect on public health of injecting treated sewage effluents directly into underground aquifers was completed in 1955 by the University of California. Settled raw sewage mixed with water was used as the recharge medium and approximated the final effluent from a secondary sewage treatment process. The sewage was injected by means of a recharge well into a 5-foot thick confined aquifer located 75 feet underground. It was found that bacterial pollutants traveled horizontally a maximum of 100 feet in the direction of normal ground water movement.

This study also showed that sewage could be successfully injected underground through the experimental recharge well at a rate equal to one-half the safe yield of the well and that periodic injection of chlorine followed by redevelopment of the recharge well maintained its ability to receive injected water. Gravel packing of the recharge well was found to be necessary. It was concluded from this experiment that direct recharge of ground waters with treated sewage effluents is a safe and hydraulically feasible method of ground water replenishment.

The recent experiments of the Hyperion Treatment Plant at Los Angeles are worthy of note because they demonstrate the great promise which exists in the use of highly treated sewage effluents to recharge ground water sources. Consideration of the utilization of Hyperion sewage effluent stems from plans by the Los Angeles County Flood Control District to construct an 11-mile fresh water barrier to prevent salt-water intrusion from the Pacific Ocean into the valuable and rapidly shrinking ground water supply, which is suffering an estimated overdraft of 210,000 acre-feet per year.

A large supply of water at a reasonable cost is required for this purpose. It would serve the dual purpose of preventing salt water intrusion and adding to the ground water supply. The two major sewage collection systems serving Los

[30] Task Group Report, "Developments in Artificial Ground Water Recharge," J. AWWA, *50*, 868 (July 1958).

[31] "Studies in Water Reclamation," Technical Bulletin No. 13, Sanitary Engineering Research Laboratory, University of California, p. 12 (July 1955).

Angeles are discharging sewage effluent into the ocean at a rate of 465 million gallons daily. If this waste of water continues to increase at its present rate, it will exceed the total volume of present imported water supplies before the proposed new Feather River source becomes available. Worse still, the overdrafts decrease the usability of the existing ground water supply because they allow the sea water to encroach on the ground water supply, thereby increasing the salinity of the ground water beyond allowable tolerances.

Hyperion-treated sewage effluent may offer a large supply of usable water for the purposes noted above. It is estimated that while the cost of Colorado River water is more than $40 per acre-foot, reclaimed sewage from the Hyperion plant would cost less than $20 per acre-foot.[32]

The experience at Hyperion and other areas shows that surface spreading of sewage effluents offers an economical solution to replenishment of ground water supplies. One of the economies offered is that effluents discharged to surface-spreading basins require less treatment than if discharged to a receiving water such as a stream or river. The spreading basin acts as a continuation of the sewage treatment process, providing additional oxidation for stabilization of the sewage.

There are practical limits to which continued recycling can be carried if the waste waters are spread or injected into the ground water. Chlorides and other salts are added each time the ground water is used for domestic or industrial purposes and then returned to the ground water reservoir. Much remains to be learned about the degrading effect of recycling waste waters to the ground. Studies of change in the quality of aquifers over a long period of time will be required.

Where suitable land is available and water is scarce, it is quite feasible to utilize spreading of treated sewage effluent as a method of recharging ground water supplies. Recharge by injection into underground aquifers is a desirable method where land costs are high. However, this method is presently restricted to the use of highly treated effluents; otherwise clogging and consequent high maintenance and operating costs result.

Although a number of experiments have shown that bacterial travel through certain types of aquifers is limited to 100 feet or less and is not related to the rate at which the recharge is being accomplished, careful control by use of sampling wells should be maintained in all operations where potable water is taken from the recharged aquifer.

Care must be exercised in controlling the mixing of industrial wastes with sewage. It has been shown that many chemical pollutants can travel considerable distances in ground water. Therefore, toxic wastes and wastes having large chemical concentrations should not be used for ground water recharge.

The recital given above shows that much additional research and field study is needed to develop this method of reuse of waste waters. It will be necessary to satisfy official agencies and the public generally that reuse of sewage for recharge does not endanger public health. When general acceptance of sewage reuse for this purpose is obtained, it will represent an additional competitive method of developing water sources. In addition it can provide a possible source of potable or industrial supply where existing supplies are inferior or inadequate.

F. Costs of recharging ground water supplies

There are summarized below the comparative costs of recharging ground water supplies by spreading and well injection with surface waters and treated sewage. The costs of the use of and recharge with treated sewage are estimated since no large-scale operation of recharge using sewage effluent has as yet been undertaken. All of the costs apply to the southern California area and may be compared with the cost of importing alternate water from the Colorado for from $40 to $42 per acre-foot.[33]

TABLE 6.—*Cost comparisons, ground water recharge*

Recharge waters	Cost of recharge, dollars per acre-foot [1]	Type of recharge
Surface water	$2 to $8	Spreading.
Surface water (treated)	$15 to $25	Well injection.
Treated sewage	$20	Spreading.
Do	$30	Well injection.

[1] In all cases, cost of alternate water is $40 to $42 per acre-foot.

G. Improved control of artesian flows

Numerous instances exist of improper development of artesian aquifers which have resulted in the release and consequent waste of huge amounts

[32] Rawn, A. M., and Bowerman, F. R., "Planned Water Reclamation," Sewage and Industrial Wastes, 29, 1138 (October 1957).

[33] Ibid.

of usable water. Waste of valuable ground water has also resulted from the inadequate plugging of flowing wells. In addition, the release of and loss of fresh water has brought to the surface even greater amounts of saline water, with the attendant problems of pollution from high concentrations of salts.

Wastage of water from artesian wells has been controlled by the State engineers of Utah and Nevada, and by the Pecos Valley Artesian Conservancy District in the Roswell artesian basin in New Mexico. It has been shown that plugging of artesian wells to eliminate "wild wells" will result in higher artesian pressures and ground water levels throughout the areas served by the aquifer.[34]

Control of this problem can be achieved through the enactment of legislation which will make it mandatory for the driller of a well to develop new wells and plug old ones in a manner which will afford a positive means of preventing overflow. Similar legislation has proved satisfactory in controlling brine production in abandoned oil wells. Since many of the water-producing wells are of small diameter and of unknown origin, it may be necessary for the States involved to assume control of these wells and to provide personnel and funds to cap them.

H. Ground water recharge—a national need

Not only is recharge being accomplished on a local level by private industries and individual communities, but the following States have undertaken projects on a regional basis: Arkansas, California, Illinois, New Mexico, New York, Texas, Utah, Washington, and Wisconsin. The work of these States is described in some detail in a task group report entitled "Developments in Artificial Ground Water Recharge" published in July 1958, in the Journal of the American Water Works Association, pages 866 to 871, inclusive. There is a growing recognition of the need for control of our ground water resources, and the response to date has been increasing slowly on a State-by-State basis. In 1957, 42 States exercised some form of control over the quantity of water discharged to the ground. The number of experimental projects involving ground water recharge has been greatly increased and many avenues of research are being undertaken.

[34] Thomas, Harold E., "The Conservation of Ground Water," p. 61, McGraw-Hill Book Co., Inc. (1951).

In 1957, the following types of specific recharge projects were underway:

TABLE 7.[1]—*Specific recharge projects*

Type of recharge project:	*Number of States*
Municipal supplies	15
Industrial supplies	13
Irrigational supplies	5
Regional supplies	9
Total	42

[1] Task group report, "Developments in Artificial Ground Water Recharge," J. AWWA, 50, 868 (July 1958).

Because it has been reported that several municipalities may find it necessary to transport their water from 50 to 150 miles or more because of depletion of ground water, regional recharge operations will assume greater importance in future years.

Sufficient experience has been gained in the practice of recharging ground water supplies with cooling water to make it obvious that all States may require that all or part of waters withdrawn from ground water supplies for cooling purposes be returned to the same aquifer. Legislation proposed by the Wisconsin Natural Resources Commission included the following provision:

> The board may require that all or part of the water withdrawn from such wells or an equivalent volume of water from some other source be returned to the aquifer or aquifers from which such well or wells withdraw water or to an alternate aquifer, with such purification, treatment, and safeguards as are essential to prevent such recharge from deleteriously affecting the quality of underground waters.[35]

I. Underground waste disposal

In discussing the problem of artificial ground water recharge, cognizance must be taken of the growing problem of pollution and consequent impairment of ground water supplies. Length of travel of bacteria in some types of underground strata is comparatively limited. On the other hand, recent studies have shown that chemicals may travel underground for great distances. Thus, with regard to pollution of underground sources, chemical contamination is more significant than bacterial pollution. The deleterious effect of disposal of industrial and commercial wastes into the ground is beginning to receive close scrutiny because of the dangers implicit in the continuation of this practice.

[35] Muegge, O. J., "Artificial Recharging of Water Bearing Formations," J. AWWA, 50, 168 (February 1958).

Since so much of the industrial operations are near urban and suburban areas where high water demands exist, it is more likely that pollution, where it results from industrial wastes will have an important effect on local ground and surface water supplies. With the expansion of industry and the consequent increase in the demand for water, the volume of waste waters to be disposed of will increase. Since there is a growing resistance to the discharge of industrial pollutants into streams, the use of ground disposal of wastes by industry may increase.[36]

A number of recent examples of the effect of chemical contamination will illustrate how widespread and complex this problem is. Along the Ohio River an industry discharges large amounts of calcium chloride wastes into a stream. Downstream cities as far as 100 miles away are taking their water supplies from gravel deposits along the river and are adversely affected.

On Long Island, N.Y., leaching pits were used by local industries for waste discharges. Water samples taken from the aquifer underlying the area showed traces of cadmium and hexavalent chromium, which are poisonous. The industries constructed treatment plants to remove these chemicals when they learned of the potential danger of the untreated wastes.

At a chemical plant in Maryland during World War II, acid wastes discharged into a nearby estuarine swamp caused the underlying ground water to become highly acid. At other places the same underground water-bearing strata, known as the Patuxent formation, which underlies a part of Baltimore, Md., has become highly contaminated as a result of disposal of acid wastes. Although acid waste disposal has been prohibited for more than 25 years, the ground water in parts of this area has remained highly acid and is unusable for most purposes.

In Texas and several other States, a number of municipal water supplies have been contaminated as a result of improper brine disposal practices in connection with development of oil fields. Several California communities have experienced ground water pollution resulting from the introduction of various chemicals into adjacent areas, such as boron from borax, ionic acid solutions used as fungicides, and chlorides from a zeolite water softening plant which was discharging saturated sodium chloride solution into an unlined pit.

The extent of travel of the industrial pollutants is illustrated by the experience near Sacramento, Calif., where potassium and ammonium perchlorates, not normally present in ground water, were discharged into abandoned gold mining tailing pits. These wastes in perchlorate concentrations of 3,500 to 5,000 parts per million apparently have contaminated the ground water in an area of several square miles. The strength of this concentration can be appreciated when it is realized that perchlorates are toxic to plants in concentrations of 1 to 2 parts per million.

Increasing concern has been evidenced regarding the pollution of ground waters by detergents from manufacturing processes and individual homes. Sources of ground water pollution from detergents include septic tank tile fields, cesspools, oxidation ponds, and holding ponds for industrial wastes. Where the surface active agents in detergents reach a concentration of 1.5 parts per million in water supplies used for human consumption, frothing and unpleasant tastes result.

Studies of the program of ground water contamination are now underway by the U.S. Public Health Service. Much additional information is required concerning the behavior of pollutants. The statement by the American Water Works Task Group on Underground Waste Disposal and Control in 1953,[37] is pertinent to this whole problem.

> Whether or not the ground waters in question are privately owned, their protection is a matter of legitimate public interest because the waters may be expected to move, naturally and under artificial influence, to other properties, public and private; because their direction of movement is not readily ascertainable or constant, and because, once polluted, they may remain so, to the detriment of other users and even future generations.

J. Ground water—Needs and management

The available evidence does not indicate any basis for assuming that the replenishable supply of ground water for the entire Nation is declining, but rather that ground water is being used from storage in specific areas at rates greater than the natural replenishment. One of the important conclusions to be drawn from a study of ground water resources is that there is inadequate informa-

[36] Task group report, "Underground Waste Disposal and Control," J. AWWA, 49, 1334 (October 1953).

[37] Task group report, "Underground Waste Disposal and Control," J. AWWA, 45, 1295 (December 1953).

tion on ground water reservoirs on which to base quantitative estimates. Further, many areas have not been studied and thus no information is available on which to base recommendations for future development and control. An adequate inventory of existing sources of ground water and their capabilities is needed.

An intimate relation exists between ground water and surface water. Both resources are related to infiltration and soil moisture. Ground water in most areas is a related part of the hydrologic cycle of surface water. For example, the dry weather flow of streams is sustained almost entirely by discharge of water from the ground. Yet, in planning of the large developments designed to integrate all of the water resources in the watersheds such as the Tennessee Valley, Missouri Valley and the Columbia, the relation of ground water potentialities of the area to the surface water development has been almost entirely neglected.[38]

There is a continuing need for more complete and coordinated studies on a nationwide basis for hydrologic information. This must be obtained through long-range research on the significance and interrelation of the various phases of the hydrologic cycle. This information, in turn, must be transmitted to the legislative and judicial branches of the governments so that the archaic divisions of surface and subsurface water law may be eliminated.

Three important aspects of ground water management must be emphasized at all levels of government. They are: (1) controlled withdrawals, (2) improved artificial and natural recharge, (3) improvements or supplementation of existing ground water sources by importation of water.[39]

1. Where rapid exploitation of ground water has resulted in lowered ground water levels and contamination of the source by intrusion of sea water and other deleterious substances, programs of conservation can be established which control withdrawals both as to amount and location.

2. Artificial and natural recharge offers great promise for the maintenance and restoration of ground water reservoirs. Not only must the practice of artificial recharge from surface waters and waste waters be more fully developed, but the concurrent responsibility of municipalities and industries to maintain the quality of the ground water and surface sources by eliminating the introduction of degrading substances into the ground water reservoirs must be recognized.

3. A third method of utilizing ground water reservoirs is to store within them water imported from other sources. As was shown earlier, the practices which have developed for ground water replenishment where intermittent usage is possible, may be adopted with advantage in areas which are facing ground water shortage.

[38] Thomas, Harold E., "The Conservation of Ground Water," p. 229, McGraw-Hill Book Co., Inc. (1951).

[39] Ibid., p. 288.

Location and Evaluation of Ground Water Supplies

Many of the modern techniques of ground water location have been adopted from methods developed by the petroleum and mining industries. A number of these new developments in the field of geophysics are proving of great value in underground exploration for water as well as other natural resources. In earlier years, it was customary to examine the general geology of an area, and with information obtained by drilling test holes or by examining existing well records, to estimate the availability of ground water.

Because the demand for water has outstripped available supplies in some areas, it has been necessary to move into new areas where ground water occurrence is not easily ascertainable. The older methods of securing underground information proved to be uneconomical and the development of more sophisticated methods of obtaining information on the occurrence of ground water supplies became necessary. With the increasing need for development of new underground supplies and evaluation of the capacities and life of existing supplies, the use of geophysical principles offers many promising possibilities. A review is given here of the methods now available for subsurface exploration of water.

A. Electrical resistivity method

The technique which appears best suited to the problems of ground water exploration involves the measurement of the electrical resistivity of subsurface strata. Variations in resistivity depend upon the type of rock or other materials in the underground formation, the degree of saturation with ground water, and the mineral content of the water present in the formation. Coarse water-bearing materials offer greater resistance to elec-

trical currents than do fine ground materials such as clay. With experience and knowledge gained from research of the typical resistivity of soils under known conditions, it is possible to interpret resistivity records in terms of geologic structure, rock type and porosity, water content and water quality.

With resistivity surveys, successful water wells have been drilled in the Middle East in from 75 to 90 percent of well drillings made as a result of these tests. Resistivity surveys are being made in the United States in an increasing number of explorations. They have been used to locate ground water levels, to obtain relative salinities and to outline the boundaries of promising aquifers. Of a large number of test drills made after resistivity surveys were completed, the correctness of the resistivity data was confirmed in 92 percent of the cases reported.

B. Seismic refraction and reflection

The seismic method, which is losing popularity because of the success with the electric resistivity method, is an excellent means of determining depth of rock. It involves the detonation of a small charge and the recording of the travel time for the resulting direct and reflected sound or shock waves to reach instruments located at known distances from the explosion. Since the speed of the waves depends upon the type of material through which it passes, it is valuable in the location of subsurface formations. Although wave motion is higher in moist than in dry formations, the actual presence of ground water is difficult to determine since the velocities from saturated and unsaturated zones frequently overlap and are difficult to interpret with accuracy. This method has been used extensively in New England to locate ground-water supplies.

C. Electric well logging

This method was originally used by petroleum and gas companies in prospecting for new supplies of oil and gas. It has now been adopted for use in exploration for underground water resources. It consists of the measurement of electrical resistance and potential by means of electrodes attached to a drill cable in the course of drilling a well. It is possible to correlate the measurements of electrical resistance and voltage as the drilled hole passes through various strata with the presence of water-bearing formations. Other instruments can be used in the drilled hole to measure gamma ray and neutron radiation, temperatures, and velocity and direction of waterflow within the well.

Logging has been found useful for determination of types of underground formations, for locating aquifers, ground-water contaminants, stray earth currents which may produce electrolysis and corrosion, and for correlating underground formations between wells. The use of electric logging is limited to drill holes which do not require metal casing.

D. Tritium in underground water supplies

A new method of investigation based upon analysis and interpretation of the products of cosmic ray action and thermonuclear explosions shows promise in the investigation of ground waters. Data from a study of the decay of tritium, which is a hydrogen isotope three times heavier than ordinary hydrogen, can be utilized to determine the rates of flows of ground water, the degree of recharge or rate at which the ground water is being replenished, and the length of time that rain appears as ground water at the point from which the ground water is withdrawn.

Tritium combines with oxygen to form water and appears as rainwater both as a byproduct from hydrogen bomb explosions and cosmic rays. The tritium has a half life of 12.5 years and has a low energy level. Because development of modern methods for the analysis of radioactivity has made it possible to detect minute quantities of tritium and to measure the rate of disintegration of this atom, and its half life compares well with the length of time involved in ground-water movement, it has been possible to determine the rate of movement and degree of recharge of ground waters.[40]

Cosmic ray action furnishes a minute but constant source of tritium, while thermonuclear explosions greatly augment the amount of tritium in the atmosphere. It has been possible to determine the rate of flow of ground water by means of measurements of the buildup and disintegration of tritium which has resulted from both of the above effects.

The significance of this new method is that it can give a positive indication of the incidence of

[40] Gustavson, R. G., "Water, the Nation's Concern Today—A Problem Tomorrow," J. of Soil and Water Conservation, 12, 262 (November 1957)

ground-water recharge, and therefore may show whether water is being withdrawn from the ground-water source at a faster rate than it is being replenished. Where knowledge is gained concerning the mining of water, it may be possible to undertake long-range programs to recharge ground-water supplies which may be the sole source of water in certain areas; or in the alternative, to begin planning to develop new sources of supply. Certainly, this new method of analysis shows promise of providing a powerful tool in obtaining additional knowledge on the action of ground waters in various parts of this country.[41]

E. Costs of ground-water exploration

Although present developments in technical methods to locate and analyze ground-water occurrence are promising, the costs of these surveys are comparatively high. However, it may be that with growing shortages of ground water in certain areas the costs may not appear too high in comparison with the necessary alternatives to be faced if ground water becomes impossible to obtain.

The surface techniques such as seismic explorations and the electric resistivity method are of most value for locating small domestic wells because they are relatively low in cost. The costs of complete electric logging are estimated to be one-half of the average cost of domestic wells. Where deposits of large volumes of water occur at rather shallow depths, or where accurate information is required on a large aquifer serving a concentrated demand, costs of electric logging are moderate.

Conservation of Water Supplies in Industry

The development and growth of industries will depend in large measure on their intelligent use of water supplies in the areas where there is a growing threat of water shortage. Water of adequate quality in sufficient quantity is of great importance to industry, because it now uses and will continue to use more water than any other segment of the economy. By 1975, industry will require nearly two-thirds of all the water produced.

Although the total water resources in the United States are not decreasing, industry tends to stratify along well-defined geographical lines, thus adding to the problem of providing adequate supplies in specific areas where shortages are already being felt. In all likelihood, the tendency toward concentration of industry and industrial water demand will continue. In some cases industry has been stimulated to conserve water as a result of actual shortages, and, in other instances, the plant's past practice of flushing away its unwanted wastes has met with stringent legal restrictions. It has been shown that under restraint to eliminate pollution there may be as much as 90-percent reduction in the quantity of water used in industry.

Through skillful design and operation of their water facilities, industries have found that they can conserve their supplies by increased utilization of existing supplies, by thorough water surveys, recharging of ground-water supplies, reconditioning their waste water, and forming industry-municipality conservation teams.

Five basic techniques of water conservation in industry are described here: (1) conservation of fresh water by substitution of sources; (2) reduction in water use and waste of waters; (3) recycling; (4) multiple reuse; and (5) reconditioning of water and wastes.

A. Conservation by substitution of source

Plants located near saline supplies or brine wells can use these supplies selectively. Every effort should be made to use saline or brackish waters for cooling processes, and special metals and materials resistive to the attack of salt water must be used.[42] Plants which use great amounts of saline waters are found along the east and west coasts. A 1955 survey by the U.S. Department of Commerce showed that saline waters amounted to over 80 percent of the water intake for industries manufacturing petroleum and coal products in California, Massachusetts, and New Jersey; petroleum and primary metals in Maryland; and chemical and allied products in Texas.[43]

Reference has already been made in earlier sections to the planned reuse of sewage effluents and the application of recharge by industry. The experience of the Bethlehem Steel plant described in another section exemplifies two conservation measures described here: (1) successful use of large

[41] Von Buttlar, Haro, "Investigating Ground Water by Analysis of Atmospheric Tritium," J. AWWA, 50 (November 1958).

[42] "Water for Industrial Use," p. 13, United Nations Department of Economics and Social Affairs, New York (1958).

[43] Annual Survey of Manufacturers, 1953, pp. 127-130, U.S. Department of Commerce (1955).

quantities of saline supplies; and (2) direct reuse of treated sewage effluents.

B. Reduction in water waste

Industry can reduce its water requirements without the need for special, costly equipment. A simple and effective device to insure conservation of water is to install meters. Meters will show how much water is being wasted when manufacturing processes are stopped. Losses from a leak in a single plumbing fixture can exceed 100,000 gallons per day. In one plant it was found that 117 water fountains flowed continuously, wasting an estimated 30 million gallons of treated water per year. In a large steel mill it was found that over 3 million gallons of water per day were lost as a result of leaking pipelines. The value of maintenance and leakage control can be great in many instances, and substantial savings can be realized from such control.

An important method by which water waste can be reduced is to provide manual or automatic valves to stop the flow of process, cooling or rinse water when the machine is not used. Another possible method of saving water is to use water-controlling devices which utilize different sizes of orifices to limit flows through supply lines as required.[44]

Another effective method of restricting water waste is to install thermostatically controlled valves on machine cooling systems. Instead of the water streaming through, thermostats can retain the water within limited temperature ranges. In one plant, water requirements were reduced as much as 70 percent with the use of this method.

C. Recycling

The procedure of reusing water over and over again for the same process can serve to reduce consumption. In Ohio a roller-bearing plant reduced its gross water intake by two-thirds by installing a recycling system. To accomplish this, it was necessary to install a cooling tower and cooling pond to reduce the temperature of the water before reuse.

The use of recycling produces changes in the quality of the water because of the concentration of salts and other materials resulting from evaporation of the water in heat dissipation. Additional treatment therefore becomes necessary. Industry must accept these costs as part of the cost of developing their products with more expensive raw materials.

D. Multiple reuse

This plan, known also as stepwise use of water, may result in dramatic reductions in water usage. It involves the reuse of water in a sequence where the initial cold water is used where low temperature cooling is required, after which the warmer effluent is directed to processes where warmer water may be used; mixing the warmed water with new cold water also is effective in conserving water. Another aspect of multiple use of process water is to introduce it to the cleanest materials first, and then in turn to the dirtiest materials. These procedures have resulted in large reduction in water usage without injury to the efficiency of the processes used or to the quality of the products manufactured.

An outstanding example of the multiple reuse technique is in the Fontana steel plant in California. The company reuses its water so effectively for a number of manufacturing processes that the intake of water is only about 1,100 gallons per ton of steel produced, compared with an industrywide average consumption of 65,000 gallons per ton of steel. It is worth noting, however, that this detailed attention to reuse is not only the result of imaginative management but of high local scarcity of water in early operations of the mills.

E. Reconditioning of wastes

Industry has found that it can reclaim water formerly going to waste by simple screening and sedimentation processes. The development of new techniques for reconditioning waste waters has in many cases reduced the strength of industrial wastes. Such developments include the more extensive use of ion exchange methods. Another important and simple measure is the segregation of wastes, with unusable portions given specific treatment at various points of discharge. Control of liquid wastes in industry has become as important as the development of new water supplies. Where wastes continue to be extracted and flushed away, either to surface or ground waters, to the detriment of potential users, it is essential that new regulations be enacted or existing laws enforced by local and State governments to insure that the water sources are not endangered.

[44] Watson, K. S., "Need for Water Management Program in Industry," J. AWWA, 47, 973 (October 1955).

Control and Reclamation of Saline Waters

Saline waters represent an enormous potential supply of usable water. At present, however, the high cost of desalting highly mineralized inland rivers or coastal waters makes it more feasible to: (1) control intrusion of saline waters into surface and underground water supplies, (2) demineralize those waters having the lowest amount of salt content.

A large percentage of the surface water in water-short areas is contaminated by a relatively small amount of highly mineralized water derived from very limited areas. In the western part of the country, such pollution generally may be traced to natural salt deposits, brines from oil-fields and salts from irrigated lands. In the eastern part of the country a preponderant portion of salt pollution of surface streams is derived from industrial wastes, and to a much smaller degree, from domestic wastes.

A. Demineralization of domestic and industrial wastes

Demineralization of surface and underground sources having salt contents in the vicinity of 1,000 parts per million would be an economic method of obtaining water if the recovery could be accomplished at costs which compare with conventional sewage treatment or water purification methods.

Useful comparisons of salt contents, in parts per million, are as follows:

Fresh water: 0 to 1,000.
Sewage effluents: Fresh water plus 100.
Brackish water: 1,000 to 4,000.
Salted water: 4,000-plus.
Sea water: 18,000 to 35,000.
Great Salt Lake: 200,000-plus.

Since the cost of demineralization is generally proportional to the mineral content of the water, it is much more economical to reclaim waters only slightly polluted with salts than to utilize expensive conversion facilities to convert to fresh water those waters containing heavy salt concentrations.

The cost for conversion of water having 10,000 parts per million of salts is about $40 per acre-foot, compared with a cost of conversion of only $4 per acre-foot for water having a content of about 855 parts per million.

Desalinization of domestic and industrial waste waters not only is more economical than reclamation of brackish water but in addition does not create a new problem of waste disposal. Salt collected from demineralizing 800 million gallons per day of domestic wastes having 500 parts per million of salt would amount to 650 tons per day. The salt from an equal quantity of brackish water containing 3,000 parts per million of salt would equal 3,900 tons per day.

Acceptable water for industrial use may easily be obtained from waste waters having low-salt content for a cost of $133 per million gallons. To reclaim an equivalent usable water from ocean water containing 20,000 parts per million of salt would cost not less than $750 to $1,750 per million gallons.

B. Dilution of saline water with higher quality water

Although it is not presently practiced except on a very limited scale in the United States, it has been shown that waters of poor quality can be blended with higher quality waters to produce a satisfactory supply for domestic, industrial, and agricultural uses.

Industry can and must seek more of its water supply, especially cooling water, from saline sources. The Gulf Oil Co. at Port Arthur, Tex., mixes 1,600 parts of brackish water with 181 parts of fresh water by volume. The blended water is then demineralized by ion exchange and used for cooling purposes.

Diluted saline waters are used in agricultural irrigation with excellent results. Where soil properties and drainage conditions permit, waters of high salinity may be used by mixing with other waters in such proportions that the mixture applied to the land is within reasonable limits. Where blending prior to application is not practicable, sufficient diluting fresh water must be discharged into the irrigation area to prevent an accumulation of salts.

A notable example of successful water conservation in agriculture with the use of blended waters is currently being practiced in Israel. Under a planned water management program, designation is made of the appropriate mixture of saline and fresh water for specific farming operations and crops. Vegetables such as beets and spinach and salt-resistant strains of forage crops such as alfalfa can grow and thrive on diluted saline waters.

Since domestic and industrial wastes are available in quantity in many parts of the country, and much of these wastes are of better quality for use in industry and agriculture than brackish or sea waters, additional means of exploiting these supplies will be developed. Mixing of saline and fresh waters to the highest degree possible in industry and agriculture offers promise of adding additional supplies of water to areas where there is a shortage of fresh unpolluted water.

PART 2. SELECTED ABSTRACTS AND REFERENCES

This section (pt. II) presents information resulting from a review of thousands of papers and abstracts. A selected listing of the literature on water sources, use, treatment and distribution is more specifically described under the following headings:

1. Treatment and Reuse of Domestic Waste Water.
2. Treatment and Reuse of Industrial Waste Water.
3. Ground Water Recharge and Recovery.
4. Surface Water Conservation.
5. Control and Reclamation of Saline Water.

The selected references are listed consecutively for each section.

1. TREATMENT AND REUSE OF DOMESTIC WASTE WATER

Today 70 million people in the United States are drinking from sources also used for sewage disposal, and water reutilization is rapidly increasing.[1] The increase in the rate of reuse is related to the population growth. There are now more than 177 million people in the United States, and there will probably be 275 million by 1980.[2]

Philosophy of sewage reclamation

Health, esthetics, and economies are paramount in the planned utilization of domestic waste water. The disposal of organic refuse of human origin has been a problem since time immemorial. The ancient Persians, years before Moses, forbade the discharge of organic filth into their rivers.[3] This historical tendency of population centers to pollute water and the land is counteracted by advancing sanitation standards.

Public health aspects.—All domestic and many industrial waste waters may be expected to contain either, or possibly both, disease-causing organisms and toxic materials. If edible crops are contaminated with untreated sewage, there is the possibility of transmitting infectious organisms as well as viruses.[4–9]

Esthetic considerations.—There should be no esthetic problem if domestic waste waters are collected, reclaimed, and reused properly.

Economic justification.—The economic considerations have been aptly put:

> If sewage were discharged without treatment it would be equivalent to sending a 2,000-ton train of water to transport a single ton of organic solids, and then throwing the train away after making only one trip.[10]

The domestic waste waters represent a considerable volume of water. More than 125 California coastal communities discharge sewage effluent to the ocean through submarine outfalls. This represents about 66 percent of the sewage and industrial wastes produced in the State.[11] Three cities, representing 62 percent of the total, dispose 94 percent of their waste into saline waters. Two of these cities have had and will continue to experience difficulties with the importation of water and its ever-rising costs. The half billion gallons of once-used water represent the combined yield of 350 12-inch wells, each producing 1,000 gallons per minute from a depleting ground-water supply. It amounts to the water required to produce 760 tons of synthetic rubber, 7,800 tons of steel, or 620,000 barrels of petroleum products (assuming the wasteful practice of once-through cooling). Even assuming an evaporation loss

[1] White, G. F., "The Future of Arid Lands," p. 324, Amer. Assoc. Advc. of Science, Pub. 43, Washington, D.C. (1956).

[2] Seaton, F. A., "Address on Water Conservation," AWWA Natl. Conv., San Francisco, Calif. (July 1959).

[3] Klein, L., "Aspects of River Pollution," Academic Press, Inc., p. 1, New York (1957).

[4] Greenberg, A. E., Kupka, E., "Tuberculosis Transmission By Waste Waters—A Review," J. Sew. Ind. Waste, 29, 524–437 (May 1957).

[5] Baumhogger, W., "*Ascaris* Infestation in the Darmstadt and Hessen from the Point of View of the Sanitary Engineer," A. Hyg. Infekt. Kr. 129, 488 (1949).

[6] Schroeder, H., "The Problem of Worm Eggs in Sewage of Berlin," Gesundheits Ing., 70, 10 (1949).

[7] Wilson, H., "Diseases From Sewage," Publ. Health, 13, 14, 332-339, 13-20, Johannesburg (1949, 1950).

[8] Bloom, H. H., Mack, W. N., Mallmann, W. L., "Enteric Viruses and *Salmonella* Isolation," J. Sew. Ind. Waste, 30, 1455-1468 (December 1958).

[9] McKinney, R. E., Langley, H. E., Tomlinson, H. P., "Survival of *Salmonella Typhosa* During Anaerobic Digestion," J. Sew. Ind. Waste, 30, 1469-1477 (December 1958).

[10] McGauhey, P. H., "The Why and How of Sewage Effluent Reclamation," Water and Sewage Works, 104, 265-270 (June 1957).

[11] Rawn, A. M., Bacon, V. W., "Organization and Accomplishments of the California Water Pollution Control System," J. Sew. Ind. Waste, 29, 201-209 (February 1957).

of 50 percent, this amount of water could readily be used to irrigate 100,000 acres of land.

By 1975 it is estimated that the use of water will reach a record high of 453 billion gallons daily.[12] Based on present standards, only 1 percent of the municipal waste water would be reused directly as industrial water.[13]

In 1975, 274 million gallons of domestic waste waters will be produced daily in Texas by three-fourths of the State's population concentrated in the eastern third of the State.[14] This area includes the major cities of the State and 70 percent of the population. Based on a conservative estimate of 25 percent reclamation and on current values of $133 per million gallons [15] the total earnings would be in the order of $9,000 per day.

Reuse of sewage by domestic systems

The two cases most widely studied in the United States illustrating reuse of highly polluted waters are Ottumwa, Iowa, and Chanute, Kans.[16] [17]

Since 1940 most of the population increase of 132 million to 175 million has been in urban areas. In effect, increased population means more effluent and less pristine diluting water. The population dependent on public water supplies has risen from 82 million to 117 million.[18] [19]

There have been reports about operating troubles due to synthetic detergents at some waterworks obtaining their supplies from rivers at times of low flow.[20] As an example, water for Osawatomie, Kans., is taken from the Marais des Cygnes River, and large amounts of foam occur when the detergent concentration exceeds 3 to 3.5 parts per million in the water supply.[21] In Appleton, Wis., water is obtained from the Fox River which receives primary treated sewage from 2 cities located only 5 miles upstream and having a combined population of 25,000 persons. Furthermore, Lake Winnebago, which feeds the Fox River, receives treated sewage from an additional 75,000 persons. The detergent apparently decreased the palatability of the water and increased chemical requirements for coagulation.[22] As little as 1 part per million of synthetic detergent in a stream can cause foaming in the stream, a problem both here and abroad. In England, foam has been particularly troublesome in the River Lee.[23] [24]

An indication of the amount of human contamination in a water supply or the lack of prior treatment is the coliform count in the raw water. A survey of 27 water treatment plants in 17 States reported that 3 plants had maximum annual arithmetical average coliform counts (MPN/100 ml) between 0 to 4,900, 5 plants between 5,000 to 9,900, 15 plants between 10,000 to 49,000, and the remaining 4 plants between 50,000 and 1-million-plus.[25]

In the heavily industrialized areas of Europe sewage effluent is recycled indirectly into the municipal system. In Germany the Ruhr River is a source of public water supply, but it is so heavily polluted that the water is not collected directly from the stream but permitted to percolate through some permeable sands and gravels where it is collected in wells dug in the banks of the stream.[26] As a matter of fact, 80 percent of the population in Germany has piped water; 80 percent of this water is pumped from underground, 15 percent is river water and 5 percent lake water. Much of the ground water comes indirectly from the rivers. Germany is not alone, because all the countries in central Europe use their rivers, particularly the Rhine, as a means of transporting their wastes. The Netherlands, the last user of the Rhine, has a great need for the water. The Rhine, with all its pollution, delivers

[12] Report Water and Sewage Industry and Utilities Division, Business and Defense Service Administration, Department of Commerce, 12 pp. (1958).

[13] Connell, C. H., Berg, E. J. M., "Industrial Utilization of Municipal Waste Water," J. Sew. Ind. Waste, 31, 212–220 (February 1959).

[14] Gloyna, E. F., Drynan, W. R., Hermann, E. R., "Water Re-Use in Texas," J. AWWA, 51, 768–780 (June 1959).

[15] Nichols, M. C., "Industrial Use of Reclaimed Sewage Water at Amarillo," J. AWWA, 47, 29 (1955).

[16] Brown, Horace A., "Super Chlorination at Ottumwa, Iowa," J. AWWA, 32, 1147 (1940).

[17] Metzler, D. F., et al, "Emergency Use of Reclaimed Water for Potable Supply, at Chanute, Kansas," J. AWWA, 50, 1021–1060 (August 1958).

[18] Picton, W. L., Business Service Bulletin 136, Business and Defense Services Administration, U.S. Dept. of Commerce (January 1956).

[19] Thompson, E. T., "The Worst Public Works Problem," Fortune 58, 102 (December 1958).

[20] Anon., "Effect of Detergents on Sewage and Water Treatment," Chemical Engineering News, 31, 1072 (1953).

[21] Culp, R. L., Stolengerg, H. A., "Synthetic Detergent Pollution in Kansas," J. AWWA, 45, 187–195 (January 1953).

[22] Cross, J. T. et al., "Effect of Synthetic-Detergent Pollution," J. AWWA, 42, 17–25 (January 1950).

[23] Metropolitan Water Board, "Report on Discharge of Synthetic Detergents to Rivers with Special Reference to the River Lee," Surveyor, London, 112, 73 (1953).

[24] Roberts, F. W., "Some Residual Effluent Problems," Wat. Sanit. Engr., 5, 13–15 (1954).

[25] Walton, G., "Relations of Treated Methods to Limits for Coliform Organisms in Raw Waters," J. AWWA, 48, 1281–1289 (October 1956).

[26] Hillier, W. H., "Presidential Address," J. Inst. Sew. Purif., pt. 4, 345–358 (1958).

three times as much water to the Netherlands as does rainfall.[27]

There is another example of indirect use near Washington, D.C. Fort Belvoir takes its drinking-water supply from Accotink Creek, the receiver of treated effluent from the cities of Fairfax and Vienna, Va.[28] The predicted 1980 population and discharge into the creek are 60,000 and 715 million gallons per day, respectively.[29]

Only about 1 percent of the municipal waste water in the United States is currently reused directly as industrial water supply.[30]

Practical considerations.—From an economic point of view both reclaimed domestic and industrial wastes have more value to industry than any other prospective user.[31] Municipal waste waters may be somewhat degraded, but are quite adequate for certain cooling and boiler feed waters.

As a case in point, a petrochemical manufacturer in the southwest had a choice between the use of well water and sewage effluent. In this case the municipality agreed that the amortized cost of an activated sludge process unit prorated for the manufacturer's percent of the effluent would be $600 per million gallons.[32] The total cost for using city water was $630 per million gallons.

Another scheme which helps to reduce the costs is to design waste-water reclamation plants upstream from the central sewage-treatment plant.[33]

Current practices.—United States: The major industries which have used or are now using sewage effluent are listed in several publications.[34-36]

[27] Key, A., "Pollution of Surface Water In Europe," Bull. World Health Org., 14, 506, 852-948 (1956).

[28] Saunders, G. W., Jr., "Pure Enough for the Military," American City, 74, 86-88 (February 1959).

[29] Wolman, A. et al., "A Clean Potomac in the Washington Metropolitan Area," Report to Interstate Commission on Potomac River, p. 19 (October 1957).

[30] Connell, C. H., Berg, E. J. M., "Industrial Utilization of Municipal Wastewater," J. Sew. Ind. Wastes, 31, 212-220 (February 1959).

[31] McGauhey, P. H., "Economic Worth of Reclaimed Water," 68, Proc. Conf. on Water Reclamation, Univ. of Calif., Berkeley (January 1956).

[32] Levy, D., Calise, V. J., "Fresh Water from Sewage," Consulting Engineer, 12, 100-105 (January 1959).

[33] Rawn, A. M., Bowerman, F. R., "Sewage—A Raw Water Supply," Water and Sewage Works, 103, 463-466 (October 1956).

[34] Merz, R. C., "A Survey of Direct Utilization of Waste Waters," Pub. No. 12. Calif., State Water Pollution Control Board (1955).

[35] Merz, R. C., "Continued Study of Waste Water Reclamation and Utilization," Pub. No. 15, Calif. State Water Pollution Control Board (1956).

[36] Merz, R. C., "Continued Study of Waste Water Reclamation and Utilization," Pub. No. 18, Calif. State Water Pollution Control Board (1957).

[37] Bush, et al, "Waste Water Reclamation and Utilization," Pub. No. 9, Calif. State Water Pollution Control Board (1954).

[38] Connell, C. H., Berg, E. J. M., "Industrial Utilization of Municipal Water Waste," J. Sew. Ind. Wastes, 31, 212-220 (February 1959).

One of the first companies to use domestic waste effluents in the United States was the Champlin Refining Co. at Enid, Okla. This plant, like the copper-mining plants at Santa Rita and Hurley, N. Mex., had no choice. Septic tank effluent is used as process water and reclaimed a second time at the precipitating plant.[39]

In water-short areas the quality of effluent varies greatly. The analyses of the sewage effluent as shown in table 1 shows the range of quality, primarily resulting from initially poor quality of municipal waters.

The Sparrow's Point, Md., plant of the Bethlehem Steel Co. is in a tidal location and has available an unlimited supply of cooling water, and about 590 million gallons per day is used. However, a chloride content of 4,000 parts per million renders this bay water unsuitable for many purposes.[40-41]

TABLE 1.—*Sewage effluent quality*[1]

[Representative analyses parts per million, excepting pH]

Test	Amarillo, Tex.	Odessa, Tex.	Los Alamos, N. Mex.	Enid, Okla.	Las Vegas, Nev.
Total solids	623	1,012-1,564	----------	700-900	856-1,026
Suspended solids	10	12- 44	25	50- 75	----------
Chloride as NaCl	132	535	----------	370-495	155- 254
Sulfate as Na_2SO_4	113	520	----------	110	486- 578
Alkaline as $CaCO_3$	310	270- 480	150	400-500	----------
Total hardness as $CaCO_3$	296	400	40	150-230	440- 476
Silica as SiO_2	79	10- 40	60	30	18- 33
Phosphate as PO_4	20	75- 110	15	40	6- 18
Ammonia nitrogen	12	10- 12	3	----------	----------
Nitrate nitrogen	5	----------	15	----------	----------
BOD	10	5- 29	20	70- 90	10- 30
pH value	76	7.5- 8	7	8.4	----------

[1] Connell, C. H., Berg, E. J. M., "Practice and Potentials in Industrial Utilization of Municipal Waste Water," Proc. 13th Indus. Waste Conf. 227-242, Purdue Engr. Bull. 96 (1958).

Where the sewage is to be used for boiler water as at the plants in Big Springs, Amarillo,[42 43] and Odessa, Tex.,[44] conventional techniques for reducing hardness, phosphate, silica and total solids are used, with slight modifications.

Softening by lime-soda processes is more difficult with sewage effluents than most waters. How-

[39] Editorial staff, "Copper Mining Plant Squeezes Water Dry," Public Wks. 88, 6, 125-126 (1957).

[40] Wolman, A., "Industrial Water Supply from Processed Sewage Treatment Plant Effluent at Baltimore," Md., Sew. Works, J. 20, 15 (January 1948).

[41] Shingledecker, C. W., "Sewage Effluent as Industrial Water," 187-197, Iron and Steel Inst. Report No. 61, London (1958).

[42] Scherer, C. H., "Waste Water Transformation at Amarillo—Municipal Phase," J. Sew. Ind. Wastes, 31, 1103-1106 (September 1959).

[43] Alexander, D. E., "Waste Water Transformation at Amarillo—Industrial Phase," J. Sew. Ind. Wastes, 31, 1106-1108 (September 1959).

[44] Sullivan, T. F., "Sewage Effluent Used for Industrial Water," ASCE, San. Eng. Div., 84, SA 3, 1679 (1958).

ever, if the sewage is freed from carbon dioxide and bicarbonates, reaction efficiencies can be increased.[45 46]

Sewage effluents have also been used in conjunction with water flooding for oil recovery. This is not always practical because oil fields are not ordinarily located near populated areas.[47 48]

European practices.—Several industries in the United Kingdom have utilized sewage effluents. Sewage effluent from the Birmingham, Tame, and Rea District Drainage Board has been used in power station coolers and condensers.

At Stoke-on-Trent a very large portion of the effluent is used for cooling at a power station.[49] The phosphate is controlled by aeration of the effluent and precipitating the phosphates in the presence of iron salts, with 80 percent removal. Orthodox lime-soda softeners lessen hardness and further reduce phosphates (below 1 part per million). Chlorine for disinfection and antifoam agents for counteracting detergents are used.

The Appleby-Frodingham Steel Co., a large integrated plant, uses softened domestic sewage effluent as cooling water. Raw effluent is used for coke quenching, mill roll cooling, general washdown, etc. Water conservation measures are very rigid at this plant, which has a goal of producing 1 ton of ingot steel per 1 ton of water.[50]

Agricultural use of sewage effluents

The oldest method of sewage disposal is land treatment. This is a method that can be combined with agricultural practices. The city of Bunzlau in Silesia had a public sewage plant incorporating land treatment as early as 1543.[51]

As reported in California, the combined population of 74 communities and sanitary districts and 32 public and private institutions irrigating with sewage effluent was only 250,000 people in 1954.[52] In the same State today water usage is 90 percent for agriculture; consequently, the entire sewage effluent of the State would only be about 8 percent of the total needed. Yet, if the entire effluent were utilized it could irrigate 100,000 acres, equal to 20 percent of the 2 million acre-feet of annual overdraft of ground water. In 1950, 3.7 million acres were irrigated in Texas; 66 percent of this water came from ground water sources.[53]

Beneficial uses.—European, middle eastern and American experience show that sewage effluent as reclaimed water can be safely used to grow grains, cotton, hay, fruit trees, and grass.

Methods of application.—The spray system and broad surface method are the types of sewage irrigation generally used. In addition there are the ridge and furrow, flooding, and subsurface methods.[54]

Hygienic aspects.—A great deal of work has been done to establish the problems of using human wastes for fertilization of fruits and vegetables.[55–61]

In one investigation, it was found that when raw sewage containing typhoid-paratyphoid groups was sprayed on grasses the wind carried the spray a considerable distance, infecting the grass for at least 6 weeks. On the other hand, no pathogens were found on grass fertilized with stabilized sludge.[62]

[45] Newton, C. D., "Softening of Domestic Waste Water," Thesis, U. of Texas, Austin, Tex. (June 1959).

[46] Stones, T., "Studies on Lime Precipitation at Salford," J. Inst. Sew. Purif., pt. 4, 395–400 (1954).

[47] Smith, G. C., personal communication, Magnolia Pet. Co. (1957).

[48] Gloyna, E. F., "Report—Treatment of Sewage for Water Injection," submitted to Magnolia Petroleum Co., Dallas, Tex. (1957).

[49] Jenkins, S. H., discussion, water pollution meeting, p. 195, "Air and Water Pollution in the Iron and Steel Industry," Special Report No. 61, The Iron and Steel Inst., London (1957).

[50] Cook, G. W., "The Extent of Water Pollution in an Iron and Steel Works and Steps Taken Towards Its Prevention," 177–186, Spec. Rep. No. 61, Iron and Steel Inst., London (1957).

[51] Reynolds, R., "Cleanliness and Godliness," p. 59, Allen and Unwin, London (1943).

[52] Krone, R. B., McGauhey, P. H., and Gotaas, H. B., "Direct Recharge of Ground Water with Sewage Effluents," Proc. ASCE, Paper 1335, 1–25 (August 1957).

[53] Report, "Water Supply and Texas Economy," 83d Cong., U.S. S. Doc. No. 57 (1953).

[54] Skulte, B. P., "Irrigation with Sewage Effluents," J. Sew. Ind. Wastes 28, 36–43 (January 1956).

[55] Rudolfs, W., Falk, L. L., Ragotzkie, R. A., "Contamination of Vegetables Grown in Polluted Soil. I. Bacterial Contaminations," J. Sew. Ind. Wastes 23, 3, 253 (March 1951).

[56] Rudolfs, W., Falk, L. L., Ragotzkie, R. A., "Contamination of Vegetables Grown in Polluted Soil. II. Field and Laboratory Studies on *Endamoeba* Cysts," J. Sew. Ind. Wastes, 23, 4, 478 (April 1951).

[57] Rudolfs, W., Falk, L. L., Ragotzkie, R. A., "Contamination of Vegetables Grown in Polluted Soil. III. Field Studies on *Ascaris* Eggs," J. Sew. Ind. Wastes, 23, 5, 656 (May 1951).

[58] Rudolfs, W., Falk, L. L., Ragotzkie, R. A., "Contamination of Vegetables Grown in Polluted Soil. IV. Bacterial Decontamination," J. Sew. Ind. Wastes, 23, 6, 739 (June 1951).

[59] Rudolfs, W., Falk, L. L., Ragotzkie, R. A., "Contamination of Vegetables Grown in Polluted Soil. V. Helminthic Decontamination," J. Sew. Ind. Wastes, 23, 7, 853 (July 1951).

[60] Rudolfs, W., Falk, L. L., Ragotzkie, R. A., "Contamination of Vegetables Grown in Polluted Soil. VI. Application of Results," J. Sew. Ind. Wastes, 23, 8, 992 (August 1951).

[61] Muller, G., Infection of Vegetables by Application of Domestic Sewage as Artificial Rain," Stadtehygiene, 8, 30–32 (1957).

[62] Muller, G., "Pollution of Irrigated Grass with Bacteria of the Typhoid-Paratyphoid Group," Lit. Ber. Wass. Abwass. Luf u. Boden, 4, 330–331 (1955).

State legislation varies considerably with respect to irrigation with sewage effluent. Most Western States have restrictions similar to those of Texas,[62] although some have no laws and others are more lenient, i.e., raw sewage should not be used on any crop and primary effluent should not be used on crops for human consumption. Complete treatment is preferred for feed and pasture crops used for animal consumption. However, actual consumption of sewage effluent by cattle is common.[64] California permits the use of sewage effluent on all crops provided it is properly disinfected and meets bacterial standards equivalent to drinking water.

In the United States over 2,200 sewage treatment plants serving 38 million people are equipped to chlorinate. Since 1948, the number of treatment plants using chlorination schemes has increased 70 percent, and the population served by plants employing chlorination has increased 110 percent.[65]

Foreign practices.—Sewage farming and fertilization practices have been developed to a point in some countries where the returns from such endeavors are a significant contribution to the national economy. Extensive documentation on sewage use for irrigation may be found in three reports prepared for the California State Water Pollution Control Board.[66]

In Israel, sewage is expected to supply 10 percent of the anticipated 400 billion gallons required for irrigation of 50,000 acres. The effluent will soon be transported from Tel Aviv to the Negev some 60 miles away.[67] By raising the water table salt water intrusion is also controlled.[68]

In England, where water for irrigation purposes is not such a serious problem, there is a great deal of interest in the sludge from sewage treatment. The dry solids recovered from sewage plants in Wales and England is about 800,000 tons per year. Of this amount, about 350,000 tons is applied to the land. This is equivalent to 10,000 tons of nitrogen, 5,000 tons of phosphorus (P_2O_5) and 1,200 tons of potassium (K_2O). Other valuable materials such as organics in sewage amount to 17.5 million tons per year.[69]

In Scotland the city of Aberdeen operates several sewage farms which apparently function well.[70]

As an example of the political interest in sewage farming and land disposal there is legislation in Bavaria which prohibits the use of state funds as subsidies for the construction of secondary treatment plants if it is technically and economically feasible to employ irrigation practices.[71] This legislation was enacted by a government that is pollution conscious and that has spent considerable sums of money for pollution control research.

Bremen, Germany, until recently irrigated 9,300 acres of meadow. Agricultural and industrial expansion forced the abandonment of this plot.

The city of Leipzig distributes effluent to 57,000 acres of land. Spray irrigation practices appear to be replacing ridge and furrow techniques.[72]

Berlin, Coesfield in Westphalia, and many others employ planned land disposal and irrigation in one form or another.

Sewage treatment in Italy is centered almost wholly around land disposal but is not well administered. Even in the smaller communities not having sewers, it has been the traditional custom to collect all organic wastes, animal and human, and dispose of them through land spreading. Although the treatment plant in Milan dates back to 1880, much of the raw sewage is used for broad irrigation practices.[73]

France, in contrast to Germany where 70 percent of the population is served by sewerage systems, has sewerage systems for only about 25 percent of the population. However, the Paris district, one-eighth of the total population, is fully sewered, and 7,000 hectares of land are farmed with sewage effluent.[74]

General sewage irrigation in other European countries, except for very small scale operations, is not practiced. There is insufficient land in the

[62] Helzik, G. R., "Texas Approves Irrigation of Animal Crops with Sewage Plant Effluents," Wastes Engineering, 27, 418-421 (1956).

[64] Merz, R. C., "Direct Utilization of Waste Waters," Water and Sewage Works, 103, 9, 417 (1956).

[65] Thoman, J. R., Jenkins, "Statistical Summary of Sewage Chlorination Practice in the U.S.," J. Sew. Indus. Wastes, 30, 1461-1468 (1958).

[66] Merz, R. C., "Study of Waste Water Reclamation," Calif. State Water Pollution Control Board, Pub. Nos. 12, 15, 18 (1953-57).

[67] Heukelekian, H., "Utilization of Sewage for Crop Irrigation in Israel," J. Sew. Ind. Wastes, 29, 868-874 (August 1957).

[68] Peter, V., "A Report of Present Activities in Israel," Water and Sewage Works, 105, 493 (1958).

[69] Report, Natural Resources (Tech.) Committee; Use of Town's Refuse in Agriculture, H.M.S.O., 25 pp., London (1954); J. Sew. Ind. Wastes, 28, 3, 340, Abs. (March 1956).

[70] Booth, A. G., "Presidential Address," Instn. Wat. Engrs., 11, 383-393 (1957).

[71] Skulte, B. P., "Irrigation With Sewage Effluents," J. Sew. Ind. Wastes, 28, 36-43 (January 1956).

[72] Stein, C., "Die Landwirtschoftliche Verwertung von Abwassern der Stadt Leipzig" (1942).

[73] Key, A., "Water Pollution in Europe Water Sanitation," World Health Organization Bull., 14 ,No. 5-6, 839-948 (1956).

[74] Key, A., ibid.

Netherlands, while in the other countries such as Ireland, Yugoslavia, Turkey, Sweden, Spain, etc., either a small percentage of the population is sewered or there is adequate dilution water available and no need for additional moisture.[75]

Melbourne, Australia, transports its wastes 20 miles where 14,000 acres are irrigated. In this case the sewage is not pretreated except for lagooning.[76]

U.S. practices.—Most of the irrigation projects using sewage effluent reported in the literature are in the arid Western States. This contrasts to the disposal of industrial wastes by land irrigation, where the humid east leads. Some of the areas using sewage effluent for irrigation are shown in table 2. It has been reported that 125 municipal sewage treatment plants in the United States provide sewage effluent for agriculture.[77]

Sewage farming in arid and semiarid areas is economical. At Lubbock, Tex., 2,100 acres are being farmed with secondary treated sewage. Without irrigation, 800 to 1,000 pounds of grain sorghums, 10 to 12 bushels of wheat or 175 to 225 pounds of lint cotton per acre can be produced. However, with irrigation 4,000 to 5,000 pounds of grain sorghums, 30 to 40 bushels of wheat, and 600 to 800 pounds of lint cotton per acre is possible.[78]

Likewise, at San Antonio, Tex., where 50 years of irrigation experience has been accumulated, 20 to 30 million gallons per day of sewage effluent are used to irrigate cotton, hay, and grass.

Conversion of sewage substrates to usable material

There is a considerable amount of plant and animal nutrient in both the sewage effluent and sludge. To a large extent it has been the practice of the Europeans and Asians to utilize these beneficial products, but it has not been done on a large scale in the United States. With the exception of pilot-plant research the American practice seems to concentrate more on destructive disposal and removal of nutrients.

Water reclamation studies are considering the feasibility of the following: protein recovery through algae harvesting or fish farming, recovery of mineral nutrients, utilization of organic humus, extraction of vitamins, and collection of gas.

[75] Key, A., ibid.
[76] Melbourne and Metropolitan Board of Works, Report (June 30, 1940).
[77] Koenig, L., "Economics of Water Sources," "The Future of Arid Lands," p. 325, Am. Assoc. for Advancement of Science, Washington, D.C. (1956).
[78] Gray, J. F., "Use of Reclaimed Waters in Agriculture" (unpublished) (1959).

TABLE 2.—*Agricultural and recreational use of sewage effluent* [1–4]

Location	Use
Arizona:	
Tucson	Cotton, grain, and pasture.
Grand Canyon	Lawn.
California:	
Bakersfield	Animal feed crops and cotton.
Barstow	Golf course.
Calaveras (State park).	Trees.
Camp Pendleton	Golf course.
China Lake (Naval Ordnance Test Station).	Do.
Delano	Animal feed crops and cotton.
El Cajon	Golf course.
El Toro (Marine base).	Do.
Fontana	Steel industry—process and cooling water.
Fresno	Animal feed crops and cotton.
Hanford	Do.
Mount Vernon (Sn. Distr.).	Do.
Nebo (Marine base)	Golf course.
Oceanside	(Under planning.)
Ontario	Animal feed crops and grain.
Orange County	Hay, sugar beets, dry beans, dry peppers.
Palo Alto	Golf course.
Pomona	Animal feed crops and citrus.
San Bernardino	Animal feed crops and orchards, berries.
San Francisco	Park and lawn, lake.
Twentynine Palms (Marine base).	Recreational fields.
Taft	Cotton—maize seed and cotton.
Tulare	Animal feed crops and cotton.
Visalia	Grain—walnuts, fruit, grain.
Wasco	Cotton—maize seed and cotton.
New Mexico:	
Carlsbad	Golf course.
Jal	Do.
Los Alamos	Golf course and recreation fields.
Santa Fe	Golf course.
Texas, over 200 towns, including:	
Abilene	Animal feed crops.
Andrews	Golf course (planned).
Brownsville	Animal feed crops.
Kingsville	Animal feed crops and cotton.
Lubbock	Grains, cotton.
Midland	Cotton, golf course.
San Angelo	Animal feed crops.
San Antonio	Animal feed crops, lake for wildfowl.
Nevada: Las Vegas	Golf course, lawns.
Washington: Ephrata	Corn, hay.

[1] Dye, E. O., "Crop Irrigation with Sewage Effluent," J. Sew. Ind. Wastes' 30, 825–828 (June 1958).
[2] Merz, R. C., "Waste Water and Reclamation," California Water Pollution Control Board, Reports 12, 15, 18, Sacramento, Calif. (1955–57).
[3] Texas State Department of Health, Austin, Tex.
[4] Johnson, W. E., "Not a Drop Wasted," American City, 73, 111–112 (1958).

Algae.—The conversion of waste products to a usable food substrate occurs in nature as a daily phenomenon. It is also possible in sewage treatment to convert organic and inorganic waste products into protein through the reduction of complex

compounds to carbon dioxide by the action of bacteria and utilization of this simpler fraction by algae. Those green microscopic plants may contain as much as 50 percent protein in their cells. Algae cultures in sewage waste stabilization ponds or pilot plants have produced as much as 36 tons of protein per acre per year.[79] It is estimated that 1,400 pounds of protein could be produced daily by algae cultured in domestic waste water from a population of 10,000.[80] The average field crop yield is more nearly 1 to 2 tons dry weight per acre per year.[81]

It has been shown rather conclusively, however, that separation of algae is difficult and costly, requiring extensive research and development before economical procedures can be established.[82]

Fish farming.—One of the oldest ways by which organic wastes are converted into usable food is through the medium of fish. The fish thrive on algae and other life which flourishes in an aquatic environment not too severely polluted. The dependence of Europeans, Middle Easterners, and Asians upon carp grown in waste ponds as a food supply is well known. Germany, Poland, Israel, and India use this method.[83-85]

In Germany the ponds receive settled sewage which is diluted with about three volumes of water. Prior to World War II the use of fish ponds provided the most satisfactory method of purification in Germany and was more profitable than normal farming procedures.[86]

Organic and mineral nutrients.—Sewage sludge, particularly heat-dried activated sludge, is relatively high in vitamin B–12. Activated sludge contains at least 10 amino acids essential for normal growth. The biological value based on protein intake is about 50 percent, being the same as that of any cereal. Extensive testing with vitamin B–12 extraction has been done at Milwaukee and Chicago.[87 88] It has been noted that it is possible to obtain as much B–12 from 10 tons of sludge as from 8 tons of fish oil.[89]

Of its mineral constituents, nitrogen and phosphorus are most valuable when sewage effluent is used as fertilizer. These also fertilize the diluting waters, resulting in a harmless but annoying algal growth. About 2.3 billion pounds of nitrogen and perhaps 0.6 billion pounds of phosphorus are discharged yearly in American domestic sewage.[90] The nitrogen would probably be worth about a quarter of a billion dollars if applied to the land, if geography permitted. The latent energy associated with this sewage is estimated to be 60 billion kilowatt-hours. About 75 percent of the nitrogen in sewage is estimated to remain in the effluent which does not become part of the humus or sludge.[91]

Microbiological production of sulfur from sewage sludge and high sulfur content wastes has been attempted in the United Kingdom [92] but no known attempts have been made in the United States.

Recovery of organic humus.—In South Africa, the recovery of all organic wastes for agricultural utilization is encouraged by law.[93] Possibly the largest sludge reclamation project in the United States is that of New York City Park Commission, which has used 400,000 cubic yards of sludge as top soil in Marine Park at a saving of about $1 million.[94]

Various cities in the United States and Europe dispose of their sewage sludge as heat dried or digestor effluents. This material has value as a soil conditioner.

At Austin, Tex., the activated sludge is diluted with river water and converted to algae cells during waste stabilization. The stabilized liquid and high nitrogen containing material is used to irrigate pastureland.

[79] Oswald, W. J., et al., "Studies of Photosynthetic Oxygenation," Prog. Rept. No. 8, Univ. Calif., Berkeley (January 1958)

[80] Renn, C. E., "Algae Research on Oxidation Ponds," Amer. J. Pub. Health, 44, 631–634 (1954).

[81] Oswald, W. J., Gotaas, H. B., "Photosynthesis in Sewage Treatment," ASCE, 81, Sep. No. 686 (May 1955).

[82] Steel, E. W., Gloyna, E. F., "Concentration of Radioactivity in Oxidation Ponds," J. Sew. Ind. Wastes, 27, 8, 941–956 (August 1955).

[83] Cludius, G., "Treatment of Domestic and Dairy Waste Waters in a Fish Pond Plant," Wass. u. Boden, 7, 8–9 (1955). Water Poll. Abs. 2738 (1955).

[84] Dyk, V., "Changes of O_2 in Eutrophic Fishpond During Day and Night," Ann. Acad. Techecosl. Agric. 26A, 455–460 (1953). Water Polls. Abs. (1955).

[85] Hepher, B., "On the Dynamics of Phosphorus Added to Fish Ponds in Israel," Limnol. Oceanog., 3, 84–100 (1958).

[86] Falck, T., "Construction of Sewage Fish Farms as Relief Work," Gesundheits Ing., 57, 228 (1943). J. Sew. Wks. Abs., 6, (1934).

[87] Wolnak, B., Zinn, R. E., "Vitamin B–12, Active Products from Sewage Sludge," U.S.P. 2, 833, 692; Chem. Abst. 52, 14896 (1958).

[88] Hurwitz, E., "The Use of Activated Sludge As An Adjuvant to Animal Feeds," Proc. 12th Purdue Indus. Waste Conf., 395–412 (1957).

[89] Rumpf, A., "Design and Arrangement of Town Sewage Works," Wasser. und Abwass. 74 (1956). Water Poll. Abs. 31, 2374 (1958).

[90] Ayres, E., Scarlott, C. A., Energy Sources, "The Wealth of the World," McGraw-Hill Book Co., New York (1952).

[91] Report, "Water Pollution Research," H.M.S.O., London (1950).

[92] Butlin, K. R., et al., "Sulphide Production From Sulfate Enriched Sewage Sludges," J. Appl. Bact. 19, 1 (1956).

[93] Krige, D. R., "The Future of the Sewage Purification Plant as an All Important Link Between Producer and Consumer of Food," J. Sew. Purif. Inst., pt. 1, 74 (1957).

[94] Scanlon, A. J., "Utilization of Sewage Sludge for the Production of Top Soil," J. Sew. Ind. Wastes, 29, 944–950 (August 1957).

Gas collections.—Gas, primarily methane, is another byproduct of domestic sewage treatment. Some plants in the United States utilize some of the gas produced during sludge digestion but its use is limited to the plant consumption. However, gas production and utilization has always been of importance in Germany. Some of the newer plants dry, purify, and pump the gas to the municipal gas works.[95] [96]

Advances in waste-water treatment

Biological treatment.—In Germany, because of the stronger waste, biological filters are deeper (11.5 to 13.1 feet) than in the United States. In this country deep filters (30 feet) are just beginning to be tried by those industries producing exceedingly strong organic wastes.

Waste stabilization ponds, commonly called oxidation ponds, are becoming popular treatment systems. In Texas there are now 200 or more small cities and a few larger ones using this system in conjunction with primary or roughing secondary treatment. In Austin, Tex., all of the excess activated sludge is treated in 191 acres of ponds. The total cost of the ponds was $575,000 and operating cost was estimated to be $4.80 per dry ton of sludge treated. During 1958, 112 pounds of activated sludge, dry weight, were added per acre per day, and about 65 pounds of biochemical oxygen demand per acre were added.[97] This is an inexpensive treatment device and with proper design can be made to function in almost any area where land is not a limiting factor.[98] [99]

The anaerobic fermentation processes convert the waste into gases, primarily methane and carbon dioxide. Domestic and industrial wastes which have a high biochemical oxygen demand generally respond to anaerobic treatment. Numerous modifications are available, largely in the design of high-rate digesters.

Nonbiological reactors.—Two processes now being explored, particularly with sludge treatment, are the Zimmerman process[100] and atomized suspension technique.[101] The former is a wet air oxidation process which produces settleable solids containing 90 percent ash. The estimated cost of a plant capable of oxidizing 100 tons of sewage sludge per day is $2.6 million. The atomized suspension technique provides a means of physically separating dissolved and suspended solids from solutions, sludges, or slurries, and subsequent chemical treatment of the solids by means of solid-gas contact reactions in a continuous operation. Major operating costs are fuel, if needed above that provided by the organic solids.

In the collection of the settleable solids it is becoming increasingly apparent that larger settling tanks must be provided. More solids and ground garbage are being put into the sewage and more sludge is in the effluent.

Sand filtration and micro straining.—Micro straining is a relatively new technique used for removing finely divided solids from either effluent or raw water. In Europe sand filtration or micro straining is again gaining popularity as a final polishing means, particularly before recharging underground formations with treated effluents.[102]

2. TREATMENT AND REUSE OF INDUSTRIAL WASTE WATER

At the present, industry takes nearly one-half of all the water used in the United States. Of greater importance, however, is the fact that the industrial use of water will probably double within the near future.[1]

Continued industrial concentration may be expected in the populous manufacturing belt. As an example of local industrial stratification, the industrial demand for 1980 on the Texas gulf coast is estimated as 1,124 million gallons per day, resulting in a 260 percent increase over 1954.[2]

Through skillful design and operation, industries find that the water situation may be improved by increased utilization of existing water supplies, by thorough water surveys, by recharging existing wells, by treating waste water, by installing water meters on internal lines to check wastage,

[95] Weber, W., "The New Sewage Works at Pforzheim," Staedtehygiene, 9, 161-168 (1958).

[96] Daser, W., "Enlargement of the Heilbronn Sewage Works," Ber. Abwass. Techn. Verein, No. 6, 170-179 (1955). Water Poll. Abs., 32, 667 (1959).

[97] Ullrich, A., Personal Communication (December 1959).

[98] Oswald, W. J., et al., "Algae in Waste Treatment," Sew. and Ind. Waste J., 29, 437 (April 1957).

[99] Hermann, E. R., Gloyna, E. F., "Waste Stabilization Ponds, pts. 1, 2, 3," Sew. and Ind. Wastes J., 30, 511, 646, 963 (April, May, August 1958).

[100] Zimmerman, F. J., "Sewage Sludge Treatment By Wet Air Oxidation," Proceed. 13th Indus. Waste Conf., Purdue Univ. 409-417 (1958).

[101] Ganvin, W. H., Pinder, K. L., "Applications of the Atomized Suspension Technique of Waste Effluents," Proc. 12th Indus. Waste Conf., Purdue Univ. 217-249 (1957).

[102] Hillier, W. H., "Presidential Address," The Inst. of Sew. Purif. Annual Conf. 1-11 (June 1958).

[1] Love, S. K., "Industry Requires Water—Lots of It," Ind. Engr. Chem., 48, 12, 21-45 (December 1956).

[2] Stockton, J. R., "Water Requirements Survey Texas Coastal Plain," Bur. Bus. Res., Univ. Texas, Austin, No. 187 (March 1951).

by helping to build reservoirs, and forming industry-municipality conservation teams.[3]

Reuse of domestic waste waters

An example of the availability of domestic waste is to be found in the Los Angeles area. At the present, municipal wastes amounting to approximately 500,000 acre-feet annually are dumped into the ocean. This quantity is twice the amount proposed as replenishment for the ground water recharge programs.[4]

Intraplant reuse

There are two basic ways in which industry can conserve a water supply. First, the demand for water may be reduced. Second, the amount of polluting wastes may be reduced, thereby increasing the usefulness of the diluting body of water.

Reduction of need.—In some cases industry has been stimulated to conserve water as a result of actual shortages, and in many other cases the plant's past practice of flushing away its unwanted wastes has met with stringent legal restrictions. It has been shown that under restraint to eliminate pollution there may be up to 90 percent reduction in the amount of water used.

The substitution of air for water in many cases provides substantial savings in water use. As an example, entrained air is used for cooling in the Big Spring, Tex., refinery. The air is bubbled through water which insures saturation prior to passage over the cooling fins.[5-7] One plant has reduced its water usage by 6,000 gallons per minute. Space, tower, and pumping costs have also been reduced.

Reuse in industry.—Industry's largest water requirement is for cooling purposes. As an example, it takes 3,000 gallons of cooling water (on an average) to produce 1 kilowatt of electric power or 6,000 gallons per day of cooling water to produce 1 ton of ice. A large paper mill may use 25 million gallons per day for its cooling operation.[8]

A steam electric powerplant was designed in Texas for a water use of only 1 gallon per kilowatt-hour output as compared to the average 80 gallons per kilowatt-hour. There is every indication of a marked increase in conservation of water by industry.[9]

In 1959, the petroleum industry was reported to be reusing 98 percent of plant water. Many of the industries were using at least 25 percent of their waste waters again.[10] (See table 3.)

TABLE 3.—*Percentage of water reuse by various industries*

Industry:	*Percent*
Petroleum	98
Paper and pulp	52
Chemicals and drugs	35
Autos and aircraft	25
Iron and steel	25
Stone and glass	25
Lumber and furniture	23
Miscellaneous	22
Foods, beverages	22
Optical and medical	21
Plastics	19
Toys and sport goods	19
Nonferrous metals	18
Machinery and tools	15
Apparel and textiles	14
Leather	12

The effect of reuse can be illustrated more specifically by the large water reusers. A survey of 327 industries on the Texas gulf coast, each using in excess of 20 million gallons of water per year, showed that these plants utilize 90 percent or more of the total industrial water used.[11] Furthermore, approximately 90 percent of the total industrial water demand in this group originated from nine industrial categories. The chemical, petroleum, and paper industries provided about 70 percent of the total industrial wastes. Select industries are discussed below:

1. *Reuse in the steel industry.*—One of the classic examples of water conservation through reuse is that of the Fontana steel plant in California. The plant was designed so that the water intake per

[3] Anon., "Is American Industry Dying of Thirst?" Mill-Factory, 60, 5, 81 (1957).

[4] Diemer, R. B., "Colorado River Aqueduct as a Source of Present and Future Supplies in So. California," J. AWWA, 51, 563-470 (March 1959).

[5] Editorial Review, "Cooling Tower Blowdown Wastes," Ind. Wastes, 3, 1, 24-26 (January-February 1958).

[6] Brody, S., "Pollution Control in the Petrochemical Industry by In-Plant Measures," Amer. Inst. Chem. Engrs., given Cincinnati, Ohio (December 1958).

[7] Merman, R. G., Roth, E. R., "Wastes and Water Systems Cut Cost at Atlantic," Power Engr., 62, 10, 80 (1958).

[8] Degler, H. E., "Industrial Conservation Methods for Re-Use of Cooling Water," Proc. Conf. on Water Resources, Ill. State Water Survey Bull. 41, p. 135 (1951).

[9] Report, "Water and Industry," Natl. Assn. Mfrs. Conserv. Found., New York (1950).

[10] Editorial Staff, "Water—Will the Lack of It Stop Our Progress?" Amer. Engr., 29, 9, 45 (September 1959).

[11] Gloyna, E. F., Hermann, E. R., Drynan, W. R., "Water Re-Use," Report to Bureau of Reclamation, Univ. of Texas, Austin (1957).

ton of steel is only about 1,100 gallons, compared to the industrywide average of 65,000.[12 13]

This reuse at Fontana is in contrast to the Fairless Works which uses 230 million gallons per day from the Delaware River and only recirculates possibly 80 percent of the industrial water. Treated sanitary waste water and clarified water used to concentrate clarified blast furnace flue dust are released directly to the Delaware, although waste water from the coke plant is used for quenching and is not released.

Surveys of the steel industry in West Germany, France, and England indicate that these countries, as well as the United States, are pushing toward maximum reuse of water.[14] If the quality becomes unsuitable for retention in its own particular circuit, the water is bled off into a system where a lower quality is acceptable. The water is permitted to enter the waste system only when recovery is uneconomical. The Appleby-Frodingham steel plant in England uses 6 tons of fresh water per ton of steel ingot produced but expects to decrease this usage to 1 ton of water per ingot ton of steel in the very near future.[15]

In England it has been estimated that with raw waters of comparatively poor quality and spent ammoniacal liquor from the coke ovens to contend with, the absolute economic minimum release is probably in the region of 10 percent of the total incoming fresh water.

New developments in settling waste waters containing mill scales and pickle liquor have in recent years contributed to the recovery of water. A new patent originating in West Berlin promises a sulfuric acid recovery of about 50 percent.

Extensive research in byproduct coke wastes, pickling and acid wastes, plating and cyanide wastes (all of the metals industry), is receiving a great deal of attention in the waste treatment field. The literature shows numerous papers describing methods for recovery or destruction of the polluting agents.[16–22]

2. *Reuse in the petroleum industry.*—Some of the most extensive reclamation schemes involve the use of production brines for water-flooding operations.

Since heat transfer and power production require most of the water in refinery operation the reuse factor can be very high.[23] In a refinery the reuse of cooling water by recirculation through cooling towers presents the most practicable method of conserving water. Approximately 50 percent of the heat produced in a typical 50,000 barrel per day refinery must be removed by water (1 billion BTU per hour).[24] Only 5 to 10 percent of fresh water makeup is required.

For processes other than cooling the purity of the stream water can be maintained by pollution prevention.[25] The Humble Refinery at Baytown, Tex., has decreased its daily requirements from 600 million gallons to 40 million gallons, constituting a 92.3 percent reduction.

A novel reuse scheme developed by the Sun Oil Co. is indicative of future trends.[26] This method used biological oxidation in the cooling tower for treating the waste prior to reuse. Bacterial action reduces phenols, sulfides and mercaptans.

The process wastes, other than boiler blowdown, are primarily dilute solutions containing various

[12] Lynch, R. G., "Our Growing Water Problem," National Wildlife Federation, Washington, D.C., 61 pp. (1959).

[13] Partridge, E. P., "Industrial Water: Use, Re-Use, Misuse?" ASME Pub. No. 59-SA-60, 1-16 (June 1959).

[14] Aitken, I. M. E., et al., "Water Recirculation in Steel Works," J. Instn. Water Engrs., 13, 253-303 (May 1959).

[15] Iron and Steel Inst., "Air and Water Pollution in the Iron and Steel Industry," p. 186, Spec. Reprt. 61, London (1957).

[16] Gurnham, C. F., Foulke, D. G., "Bibliography of Metal Finishing Wastes, 1956," Plating, 44, 916 (1957).

[17] Gurnham, C. F., Foulke, D. G., "Bibliography of Metal Finishing Wastes, 1957," Plating, 44 (August 1957).

[18] Black, H., et al., "Industrial Wastes Guide, By-Product Coke Industry," J. Sew. Ind. Wastes, 29, 53 (January 1957).

[19] Pasqualine, I., "Experiences in Liquid Waste Reduction at the Camden Coke Plant," Proc. Amer. Gas Assoc., 38, 505 (1956).

[20] Savage, A. P., "Solvent Waste Problems of a Large Chemical-Type Coke Plant by Cooperative Efforts," Blast Furnace Steel Plant J., 46, 705 (1958).

[21] Arden, T. B., "Ion Exchange in the Treatment of Trade Waste," Surveyor, 117, 257 (1958).

[22] Douavenza, P., "Plant for the Treatment of Plating Wastes," Metall Oberflache, 12, 22 (1958).

[23] McKee, J. E., "Report on Oily Substances and Their Effects on the Beneficial Uses of Water," Water Poll. Cont. Bd., Sacramento, Calif. Pub. No. 16 (June 1956).

[24] Howell, G. A., Simonse, R. N., et al., "Pollution Abatement Through Water Conservation-Symposium," J. Sew. Ind. Wastes, 24, 1368 (November 1952).

[25] Dahl, A. H., "Development of a Natural Water Reserve by Pollution Control," given WPRA 3rd Annual Water Disposal and Stream Pollution Conference (Oct. 1-2, 1958).

[26] Edit. Staff, "Sun, Fluor Offer New Process," Oil Gas J., 56, 5, 62 (1958).

organic compounds. These organic wastes may be toxic but generally are amenable to some form of chemical or biological treatment. Some waste waters of organic content can be burned.[27 28]

3. *Paper and allied products.*—Because of the relatively high ratio of process water to cooling water in the paper and allied products industries, there may not be a great amount of intraplant reuse. The major contribution of this industry toward water reclamation is through its pollution abatement program. The industry has spent over $100 million during the past 10 years and is currently spending over $1 million each year on research alone.[29]

One of the most fruitful sources of water for reuse is machine water from the pulp side and water extracted from the final product of the pulp-mill. This water from deckers or thickeners can be reused for diluting or thinning fresh stock for screening operations.[30-32]

4. *Chemicals and allied products.*—The major use of water in the chemical industry is for cooling purposes. Consequently, the waste water is readily reusable. A survey of the gulf coast area, predominantly petrochemical, indicated that cooling water requirements were 72 percent of the total.

The chemical process wastes represent as heterogeneous a liquid waste as can be found. However, volume control on a departmental basis and rigorous adoption of waste-water treatment processes by each plant can prevent pollution of waterways and in many cases prepare the waste for reuse.[33-37]

The petrochemical industry grosses about $5 billion per year, or 25 percent of the total chemicals industry. Consequently, it is likely to set the pattern of water reuse, particularly since a considerable amount of the production is in relatively arid areas. Many plants now use oil rather than water for quenching and shell and tube heat exchangers rather than barometric condensers.[38]

5. *Textile products.*—The textile industry does not require a significant amount of water for cooling purposes, but the available return flow is roughly 80 percent of the water intake. This flow constitutes a significant fraction available for reuse. Numerous publications have been presented on methods of treating textile wastes.[39-41]

6. *Food and kindred products.*—Due to the seasonal characteristics of the canning industry in some areas, extensive water reuse is not too likely. At the present the industry discharges about 88 percent of the process water and almost all of it is cooling water without recirculation. The total amount of waste water available for reuse amounts to about 95 percent of the total water intake. Possibly the best means of salvage is through treatment, dilution with the environment, and subsequent reuse.

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[27] Kaplovsky, A. J., "Tidewater's Delaware Refinery Waste Control and Treatment: Evaluation of Treatment Methods," J. Sew. Ind. Wastes, 31, 432 (April 1959).

[28] Pettijohn, A. R., "Disposal of Burnable Liquid Wastes," given Tex. Sec., ASCE, Austin, Tex. (Oct. 4, 1956).

[29] Saunders, H. H., "Pollution Abatement," Priorities, 21 (May 1958); abs. J. Sew. Ind. Wastes Lit. Rev., 31, 627 (June 1959).

[30] Committee on Coordination of Research, Report 1949-55, American Pulp and Paper Assoc., New York (1955).

[31] Amberg, H. R., "Re-Use of Water in Pulp and Paper Mills," TAPPI, 38, 11 (1955).

[32] State Water Pollution Control Board, "Waste Treatment and Disposal Aspects to Development of California's Pulp and Paper Resources," Pub. No. 17, Sacramento, Calif. (1957).

[33] Gutzdit, G., et al., "Treatment of Phenolic Wastes," Ind. Wastes, 4, 57-60 (July 1959).

[34] Rudolfs, W., "Industrial Wastes," Reinhold Pub. Co., New York (1953).

[35] Meinhold, T. F., Arnold, E. R., "Submerged Combustion Whips Boron-Caustic Waste Disposal Problem," Chem. Processing, 21, 7, 73 (1958).

[36] Faust, S. D., Orford, H. E., "Reducing Sludge Volume With Crystal Seeding in Disposal of Sulfuric Acid Waste," Ind. Engr. Chem., 50 1537 (1958).

[37] Mohlman, F. W., Ed., "Liquid Waste Symposium," Ind. Engr. Chem., 44, 467-552 (March 1952).

[38] Ruggles, W. L., "Basic Petrochemical Processes as Waste Sources," J. Sew. Ind. Wastes, 31, 274-282 (March 1959).

[39] Geyer, J. C., "Industrial Wastes—Textile Industry," Ind. Engr. Chem., 39, 653-656 (1947).

[40] Souther, R. H., Alspaugh, T. A., "Textile Waste-Recovery and Treatment," J. Sew. Ind. Wastes, 29, 918 (August 1957).

[41] Green, G., "Treatment of Trade Waste from British Celanese Factory at Derby," Surveyor, 116, 228 (1957).

Industrial pollution prevention techniques

It is logical to ask what industries contribute significantly to the pollution of surface waters and what type of wastes can be expected. Table 4 lists some of the industries which may cause pollution.

TABLE 4.—*Typical industries that may cause pollution*

A. Food industries:
- Beet sugar.
- Brewing industry.
- Canning industry.
- Citrus processing.
- Dairy industry.
- Distilling industry.
- Food processing.
- Meatpacking.
- Slaughterhouses.
- Starch industry.
- Sugar processing.
- Yeastmaking.

B. Mineral industries:
- Coal mining and processing.
- Coke processing.
- Gas manufacture.
- Mining.
- Petroleum industry.
- Steelmaking.

C. Process industries:
- Chemical industry.
- Fermentation industry.
- Metal plating.
- Metal processing.
- Pharmaceutical manufacturing.
- Pulp and paper industry.
- Synthetic fiber manufacturing.
- Canning industry.
- Soap and detergent producers.

D. Miscellaneous industries:
- Laundries.
- Nuclear plants.
- Powerplants.
- Transportation industry.
- Water treatment plants.
- Transportation manufacturing.

Table 5 shows the 15 industrial wastes reported to be the most troublesome, arranged in order of the number of jurisdictions reporting them as such.

TABLE 5.—*Most troublesome industrial wastes* [1]

1. Paper.
2. Dairy and milk products.
3. Tannery.
4. Textile.
5. Meat and food processing.
6. Pulp.
7. Metals.
8. Sugar beets.
9. Oil drilling.
10. Chemicals.
11. Oil refinery.
12. Distillery and cannery.
13. Wool.
14. Coal.
15. Mining.

[1] Anabele, A., Kite, R. D., "Pollution Abatement, Appraisal and Current Regulations," Chemical Engr. Progress, 44, 3-16 (January 1948).

The smaller industries rely heavily upon existing municipal waste treatment facilities; the larger industries more frequently treat their own liquid wastes. As an example, the American Cyanamid Co., which manufactures more than 800 chemical products at its Bound Brook Plant in New Jersey, constructed its own plant capable of treating 17 million gallons of waste water per day although the company could have joined a sewage authority.[42]

Interstate agencies.—There are in existence today five different Government groups in the United States responsible for the proper handling of industrial wastes. These include the Federal Government, groups of States or compacts, State governments, sanitary districts, and municipal governments. There are also five Federal laws controlling water pollution.[43]

Byproduct recovery.—The Emscher River Association in Germany has constructed at a number of coke oven works special dephenolization plants. It is claimed that the association recovers the operating costs and capital investments of the plants.

Pulp and paper mills in the State of Washington are recovering sulfur dioxide, alcohol, and powdered lignins. During the summer months a considerable amount of waste liquor is sold as a road binder and dust palliative These recovery operations are estimated to reduce the pollution load by 50 percent.[44]

When the Texas Railroad Commission and other State agencies made it mandatory for petroleum producing companies to conserve gases previously wasted during the mining of oil, a multitude of new industries were created. Previously wasted gases are now being used to repressurize formations so that oil may be mined more efficiently. The butane and propane industry has grown into a giant, supplying a large portion of the fuel for irrigation in the Southwest and winter heating in many sections of the country. The latest achievement is to liquefy the methane and transport it to England.

The oil industry utilizes much of its salt water as a repressurizing fluid. Subsurface water flood-

[42] Powell, S. T., Lamb, J. C., III, "Industrial and Municipal Cooperation for Joint Treatment of Wastes: Industry Approach and Position," Sew. Ind. Wastes J., 31, 1044, (September 1959).

[43] Bloodgood, D. E., "Treatment of Industrial Wastes in the United States," J. Inst. Sew. Purif., pt. 4, 359-370 (1958).

[44] Eldridge, E. F., "Pulp and Paper Mill Pollution Problems," Inf. Series No. 8 (1955).

ing was initiated to increase the efficiency of oil recovery.

Land disposal.—A more recent development in the disposal of industrial wastes is spray irrigation. This particular technique has proven satisfactory for the disposal of dairy wastes, food processing wastes, tanning wastes, paperboard mill wastes, and perhaps many others.[45-48]

Evaporation.—Many industries utilize solar evaporation as a means of temporary pollution abatements. The Celanese Corp. plant at Bishop, Tex., enjoys an average net evaporation rate of 1.2 g.p.m. per acre,[49] and successfully uses solar evaporation.

Evaporation and control of the solids has been successfully accomplished. The atomic energy industry uses evaporation and consolidation of solids extensively to control a most toxic waste.[50] The pulp and paper industry as well as the chemical industry and the distilling industry find that dewatering and burning, with or without catalyst, can be accomplished.

Disposal of brines and toxic concentrates into underground formations.—Several industries have experimented with disposal of undesirable nonrecoverable wastes into underground formations. One of the first installations was at Victoria, Tex. Two wells about 8,400 feet deep were drilled for disposal of some 9,000 gallons per hour of brine at a cost of $250,000. At a rate of disposal of 500,000 gallons per 24 hours, operating costs are $95 per day.[51]

The U.S. Atomic Energy Commission at various locations has effectively used underground disposal techniques for some of its long-lived radioisotopes.[52 53]

[45] Lawton, G. W., Braska, G., Engelbert, L. E., Rohlich, G. A., Porges, N., "Spray Irrigation of Dairy Waste," Sew. Ind. Waste, J., 31, 923-934 (August 1959).

[46] Ingols, R. S., "Treating Food Processing Wastes," Ind. Wastes, 3, 95 (July-August 1958).

[47] Koch, H. C., Bloodgood, D. E., "Experimental Spray Irrigation of Paperboard Mill Wastes," Sew. and Ind. Wastes, J., 31, 827 (July 1959).

[48] Eick, J. F., "Tannery Waste Disposal by Spray Aeration," Ind. Wastes, 1, 8, 271-273 (November-December 1956).

[49] Black, H. H., "Industrial Waste Treatment," Civil Engineering, 689, 96-104 (October 1955).

[50] Spec. Sub. Comm. on Radiation, Joint Comm. on Atomic Energy, 86th Cong., "Hearing on Industrial Radioactive Waste Disposal," U.S. Government Printing Office, Washington, D.C. (1959).

[51] Black, W. B., "Underground Waste Disposal," Sew. Ind. Wastes, J., 30, 669-672 (May 1958).

[52] Spec. Sub. Comm. on Radiation, Joint Comm. on Atomic Energy, 86th Cong., "Hearing on Industrial Radioactive Waste Disposal," U.S. Government Printing Office, Washington, D.C. (1959).

[53] National Academy Sciences, National Research Council, "The Disposal of Radioactive Wastes on Lands," Report Comm. Waste Disposal, Div. of Earth Sciences, Publ. 519 (April 1957).

3. GROUND WATER RECHARGE AND RECOVERY

Ground water originates from the great body of atmospheric, surface, and subsurface water which has accumulated during geologic time.[1]

For specific and quantitative investigations, ground water should be considered in conjunction with surface water—both as interrelated parts of the same resource.[2]

General description

McGuiness describes and presents a map of the entire country showing the locations of those aquifers capable of yielding 50 gallons per minute or more to individual wells.[3]

There are two component parts to ground water. One part is included in the hydrologic cycle continually taking place. Another part represents water from past precipitation which is no longer a part of the circulation within the hydrologic cycle except insofar as it is brought to the surface by man.[4] The amount of both has been estimated as 48 billion acre-feet of usable water.[5]

Geology of ground water reservoirs.—Probably 90 percent of all developed aquifers consist of unconsolidated rocks, chiefly gravel and sand.[6]

Todd lists and describes the geologic and groundwater characteristics of the 24 ground-water provinces into which the United States has been divided.[7]

Uses of ground water.—The estimated use of ground water expressed in billion gallons per day was 10 in 1935, 20 in 1945, 30 in 1950, and 46 in 1955.[8-10] The 1955 figure represents 19 percent of the total use of surface and ground water.

[1] Tolman, C. F., Ground Water, p. 27, McGraw-Hill Book Co., New York (1937).

[2] Upson, Joseph E., "Ground-Water Problems in New York and New England," Proc. ASCE, 85, HY6, 11 (1959).

[3] McGuiness, C. L., "The Water Situation in the United States with Special Reference to Ground Water," U.S.G.S. Cir. 114, 98 (1951).

[4] Ackerman, E. A., Lof, G. O. G., "Technology in American Water Development," p. 24, Resources for the Future, Inc., Johns Hopkins Press (1959).

[5] Thomas, H. E., "Underground Sources of Our Water," Water—The Yearbook of Agriculture, p. 52, U.S. Dept. Agric., U.S. Government Printing Office, Washington, D.C. (1955).

[6] Todd, D. K., "Ground Water Hydrology," p. 26, John Wiley and Sons, Inc., New York (1959).

[7] Ibid., p. 36.

[8] Guyton, W. F., "Analysis and Use of Ground Water Data," Proc. Conf. on Water Resources, Bull. 41, Ill. State Water Survey, p. 75 (1951).

[9] MacKichan, K. A., "Estimated Use of Water in the United States—1950," p. 13, U.S.G.S., Cir. 115, Washington, D.C. (1951).

[10] MacKichan, K. A., "Estimated Use of Water in the United States—1955," J. AWWA, 49, 383-387 (1957).

The predicted ground-water demands for 1975 will be 69 billion gallons per day.[11]

There is no national ground-water problem as such, but there are numerous widely scattered problem areas, each differing more or less markedly from its neighbors because of distinctive geologic and hydrologic environment and other local factors.[12]

The ground-water percentage of total use varies widely even from State to State. MacKichan tabulates use by States, showing that South Dakota obtains 76 percent of its total from ground water, while the two greatest users of ground water—California and Texas—obtain 36 and 48 percent, respectively, from ground water.[13]

The largest single demand for ground water is from irrigation, amounting to 30 billion gallons per day, or 65 percent of the national ground-water usage in 1955. Furthermore, 91 percent of this water was pumped in the 17 Western States, where arid conditions have fostered extensive irrigation development. The demands for irrigation water throughout the humid area are also going to increase in the next 20 to 30 years.[14]

The advent of the vertical turbine pump with increased pump efficiency and greater allowable pumping depths, improved internal combustion engines, and the decreasing cost of electricity have all contributed to an increased use of ground water.

The effect of this development is well illustrated in the high plains of Texas. In the years following introduction of the vertical turbine pumps, the number of wells multiplied 25 times from approximately 2,000 wells in 1940 to about 50,000 wells in 1957.[15]

Elements of ground water

Movement of ground water.—In most formations the flow of water is not turbulent but laminar. The rate of flow is directly proportional to the hydraulic gradient. The characteristics of a formation to transmit water may be called permeability or transmissibility.

Permeability is defined as the rate at which a fluid will flow through a unit area under a unit hydraulic gradient. Transmissibility is defined as the rate at which a fluid will pass through a section of unit width extending the depth of the aquifer. Values of permeability may be obtained by testing a small sample of the aquifer in an apparatus called a permeameter.[16] There is always the possibility that the laboratory sample does not perfectly represent the conditions in the field. For this reason tests may be made directly in the field by using tracers.[17] Thus the rate of water movement between wells may be obtained. Field procedures also include pumping tests and calculations.

Infiltration and percolation.—Linsley defines infiltration as the passage of water through the soil surface. Percolation is the movement of water within the soil.[18] The two are closely related since infiltration cannot continue unless percolation removes infiltrated water from the surface soil.

Factors affecting infiltration and percolation.—The infiltration capacity is affected by soil type, moisture content, organic matter, vegetative cover and season.[19] Porosity generally tends to give silt content. Pools remaining in the river after the flood indicated an average rate of percolation of 0.91 foot per day.[20]

Rates of streambed percolation in the San Gabriel River, Calif., showed rates varying from 1.8 to 19.6 feet per day.[21]

Natural recharge incidental to other operations has been reported. Field measurements of seepage losses from unlined canals in the Safford and Duncan-Virden Valleys, Arizona and New Mexico, indicate that one-third of the diverted water is recharged to ground water. Combined canal and irrigation losses total 50 percent of all diverted water.[22]

In the upper San Joaquin Valley ground-water basin in California, it was found that canal conveyance losses, excess irrigation, and percolation

[11] Picton, W. L., "Water Use in the U.S. 1900-1975," Business, Defense Service Admin., U.S. Dept. Commerce, Washington, D.C. (January 1956).

[12] Fiedler, A. G., "Importance of Ground Water in Our National Economy," Proc. ASCE, San. Engr. Div. 83, SA3, No. 1271 (June 1957).

[13] MacKichan, K. A., "Estimated Uses of Water in United States—1955," J. AWWA, 49, 386-387 (op. cit.) (1957).

[14] Beauchamp, K. H., "Potential Use of Water by Irrigation in the Humid Area," Proc. ASCE, 84, IR3, 1750-1751 (September 1958).

[15] Ackerman, Lof (op. cit.), p. 282.

[16] Todd, op. cit., p. 54.

[17] Kaufman, W. J., Orlob, G. T., "Measuring Ground Water Movement with Radioactive and Chemical Tracers," J. AWWA, 48, 5, 559-572 (May 1956).

[18] Linsley, R. K., Jr., Kohler, M. A., Paulhus, I. K. J., "Hydrology for Engineers," p. 164, McGraw-Hill Book Co., New York (1958).

[19] Ibid., p. 166.

[20] Babcock, H. M., Cushing, E. M., "Recharge to Ground Water from Floods in a Typical Desert Wash, Pinal County, Ariz.," Trans. A.G.U., 23, pt. 1, 49-59 (1942).

[21] Conkling, H., "Utilization of Ground-Water Storage in Stream System Development," Trans. ASCE, 111, 275-354 (1946).

[22] Turner, S. F., "Water Resources of Safford and Duncan-Virden Valleys, Arizona and New Mexico," U.S.G.S. Open File Report (mimeo), Tucson, Ariz., 125 pp. (1941).

from streambeds contribute approximately 55, 30, and 15 percent, respectively, of the total recharge. Direct penetration of rainfall is shown to be a negligible factor.[23]

Infiltration rates of 0.8 foot per day were indicated from surplus floodwater in the porous lava formations underlying the Snake River Plain, Idaho.[24]

Water spreading systems over some 7,000 acres of rangeland near Tucumcari, N. Mex., have been constructed to conserve water and to increase growth of grass.[25]

Artificial ground water recharge by spreading

Spreading works serve effectively to reduce evaporation and to make available a maximum amount of water at some later date. Since ground water reservoirs usually cover relatively large areas, local spreading costs may not reflect a direct benefit to any one individual, industry, irrigation district, or city.[26] Mosquito breeding may be a problem.

Methodology.—Four major techniques are used to infiltrate water into underground reservoirs. They are:

Basin.
Furrow.
Flooding.
Excavation.

Adequate geological and surface infiltration data must be obtained before a spreading facility can be analyzed. The surface covering, permeability of various underground formations, direction of formation depth, anticipated pumping pattern, quality of the water to be used, quality of the water arriving at the infiltration sites, and character of pollutants must be thoroughly investigated.[27]

The greatest advantage of the basin method is that a maximum net wetted area can be obtained. Also, basins may act as storage units for later infiltrations. Two-stage basins are used in Long Island for desilting and infiltration.[28] In other spreading operations the upper basins are periodically cleaned. When necessary the bottoms of the basin may be harrowed or scarified to break up the silt layer and to maintain better permeability.

Where a constant depth of water is maintained in a basin the rate of percolation decreases rapidly until gases in the soil have been dissolved by the percolation water. The initial rate decrease is believed to be caused by dispersion of swelling soil particles.[29]

The gradual decrease in rate that follows initial spreading is attributed to the biological activity in the soil. Where the recharge is to be seasonal, the basins can be allowed to dry thoroughly, resulting in aeration and higher average seasonal rates.[30] [31]

One of the simplest means of recharging ground water is the directed flow of water into long ditches or furrows with percolation taking place throughout the length of flow. This method is generally the same as that used in ordinary crop irrigation except that more water is applied to the field with the objective being to get much of it below the root zone.[32]

Untreated surface water.—Several States and foreign countries effectively use untreated surface water to recharge depleted ground-water reservoirs.

The costs for recharging untreated water average about $2 to $8 per acre-foot, depending upon the cost of the land. The recharge rates vary from 1.0 foot per day under unfavorable conditions to 10 to 16 feet per day under favorable conditions.[33]

Effective recharge by storm water has been accomplished by various agencies on Long Island, N.Y. There are more than 300 recharge basins under the control of Nassau County; and many others are under the control of State, town and village authorities. A system of storm sewers is used to direct the water to spreading basins, resulting in a large recharge factor and savings in cost resulting from shorter storm sewers.

[23] Bartz, P. M., "Physical Aspects of Ground-Water Use in the Upper San Joaquin Valley," doct. dissert., University of California, 234 pp., Berkeley (1949).

[24] Crandall, Lynn, "Groundwater Flows of the Snake River Plain," U.S.G.S. open file report; present annual meeting Idaho State Reclamation Association, Pocatello, Idaho (1953).

[25] Miles, W. H., "Water Spreading," Soil Conservation, 10, 4, 73-76 (1944).

[26] Greenburg, A. E., "Reclamation of Sewage Water," Am. J. Pub. Health, 42, 4, 401-410 (1952).

[27] Muckel, D. C., "Replenishment of Ground Water Supplies by Artificial Means," U.S. Department of Agriculture, Technical Bulletin 1195, 16 (February 1959).

[28] Welsch, W. F., "Conservation of Ground Water," Water, Sewage Works, 103, 468-473 (October 1956).

[29] Sanitary Engineer Research Laboratory, "Studies in Water Reclamation," Technical Bulletin 13, 14, Berkeley, Calif. (July 1955).

[30] Muckel, op. cit., p. 25.

[31] Allison, L. E., "Effect of Micro-Organisms on Permeability of Soil Under Prolonged Submergence," Soil Science, 63, 439-450 (1947).

[32] Muckel, op. cit., p. 10.

[33] Laverty, F. B., "Ground Water Recharge," J. AWWA, 44, 677-681 (August 1952).

One of the largest recharge basins drains 2,080 acres and has a capacity of 3,685,000 cubic feet. Its depth is 11 feet. The average rates of recharge in this particular locale, using heads varying from 0.5 to 9.0 feet are about 23 gallons per square foot per day. The basins are usually designed on the basis of 11 gallons per square foot per day.[34] [35]

Areas near Bountiful and Salt Lake City, Utah, have also attempted to recharge by spreading. Two creeks near Bountiful were dammed so that the excessive water would flow into canals and over permeable brushlands. About 420 acre-feet per year have been recharged by this means and the water table has risen 15 feet. Canal losses amounting to 74 percent of the initial flow in a 2-mile distance near Salt Lake City proved to be a more effective means of recharging than general spreading.[36] [37]

Porous lava formations are flooded through the use of canals along the Snake River Plain in Idaho. It was estimated that rates of 1 foot per day might be obtained. The Raccoon River in Iowa supplies water through a gallery system to the city of Des Moines. However, during low riverflows the riverbed becomes silty and yield decreases. Construction of spreading basins has increased the yield and no deterioration in the quality of the water has been experienced.[38] [39]

The Perth Amboy waterworks in New Jersey has practiced artificial recharge by spreading for more than 40 years. Large ditches have been dug adjacent to the line of withdrawal wells. It is estimated that 125,000 gallons per acre per day are infiltrated into the Old Bridge sand which lies about 80 feet below the surface of the ground.[40]

Fractured limestone areas have apparently functioned successfully in the Texas area. However, no specific data are available to show how much actual recharge was accomplished.[41]

Most artificial recharge spreading operations in California are located in the Santa Clara Valley, south San Joaquin Valley and in southern California.[42] As part of the Central Valley project in California, it is planned to divert Class 2 water at Friant Dam, convey the water 165 miles by canal, and recharge it at Bakersfield. The anticipated storage by spreading is to vary from 0.8 to 1.5 million acre-feet annually. The use of cotton gin trash will help to maintain high recharge rates.[43]

As of 1954 there were over 1,800 acres of spreading areas under control of the Los Angeles Flood Control District.[44] A unique system exists in Orange County, Calif.; 70 acres of spreading ground are used in conjunction with six recharge wells. Storm water is released over the spreading area for some infiltration and desiltation.[45] In some areas it appears to be possible to infiltrate 8 to 9 feet of water per day over the wetted areas.

Two idle gravel pits have been utilized as recharge basins at Richland, Wash. Collecting wells surrounding the recharge site and the water are used after chlorination.[46]

In Sweden it is claimed that recharge produces more palatable water by temperature adjustment, making coagulation and settling unnecessary, and the biological action in the natural aquifers affords the most suitable means for taste and odor control.[47] In one instance the wells were only 500 feet from the recharge sands. Finally, after 35 years, the highly colored and turbid water penetrated the natural sand layers and the recharge site had to be moved. The recharge rates varied from 3 to 8 meters per day.[48]

The cities of London and Moose Jaw, Canada, practice extensive spreading operations. In one case water from the Saskatchewan River is pumped to a high point from which it flows 78 miles to a large sandy recharge area.[49] [50]

[34] Upson, J. E., "Ground Water Sources on Long Island," J. AWWA, 47, 341 (April 1955).

[35] Johnson, A. H., "Conservation of Ground Water on Long Island," J. AWWA, 47, 348 (April 1955).

[36] Thomas, H. E., "Artificial Recharge of Ground Water by the City of Bountiful, Utah," Trans. A.G.U., 30, 4 (1949).

[37] Lazenby, A. J., "Experimental Water Spreading for Ground Water Storage in Salt Lake, Utah," Trans. A.G.U., 19, 402–415 (1938).

[38] Crandall, L., "Ground Water Flows of the Snake River Plain," U.S.G.S. Open File Report (1953).

[39] Buchan, S., "Artificial Replenishment of Aquifers," J. Instn. Water Engrs., 9, 119 (January 1955).

[40] Erickson, E. T., "Using Runoff for Groundwater Recharge," J. AWWA, 41, 647 (July 1949).

[41] Scalapino, R. A., "Artificial Recharge of Ground Water Reservoirs," J. AWWA, 47, 230–234 (March 1955).

[42] Banks, H. O., et al., "Artificial Recharge in California," California Division Water Resources (memo), 41 (1954).

[43] Clyde, G. E., "Utilization of Natural Underground Water Storage Reservoirs," Soil, Water Conservation J., 6, 15–19 (1951).

[44] San. Engr. Res. Lab., Univ. of Cal. "Studies in Water Reclamation" (1955).

[45] Conkling, H., "Utilization of Ground Water, Storage and Streams System Development," Trans. ASCE, 111, No. 2272, 275–354 (1946).

[46] Brunley, D. J., "Atomic Energy Town of Richland, Washington, Grows from 250 to 25,000 Population," Civ. Engr., 19, 6, 391–395 (June 1949).

[47] Alter, A. J., "Notes on Modern Swedish Water Supply and Treatment Practices," J. AWWA, 44, 387–391 (May 1952).

[48] Buchan, op. cit., p. 116.

[49] Ibid., p. 124.

[50] Barnes, A. S. L., "Conservation and Water Supply," Water, Sewage Works, 86, 4, 70 (Municipal Utilities, Toronto) (1948).

Very well designed spreading basins are operated along the Ruhr Valley in Germany. Some of these basins measure 1,300 feet in length and 100 feet in width, having a depth of 10 feet.[51] It has been estimated that basin infiltration has contributed more to ground water recharge in the Ruhr Valley than have natural ground water and riverbank infiltration together.[52]

Treated river water.—Not many treated-water spreading basins are in operation in the United States. There are many of these installations in Europe.

River water at Peoria, Ill., is given chlorination treatment before it flows by gravity into the basin. This basin was designed for 2 million gallons per day over the 6-month period when the river water temperature is below 60° F. Algal growth is eliminated by the use of copper sulfate.[53]

In Sweden most of the water is so highly polluted that some form of pretreatment is necessary. In Karlshoga, Sweden, water is given rapid sand filtration before spreading. Rotating drum screens and rapid sand filtration are used at Estilstuna, Sweden.[54]

The city of Bamberg, Germany, provides primary settling before utilizing recharge basins. Rates up to 7.2 feet per day are continually obtained. Frankfurt has been using spreading techniques preceded by slow sand filtration since 1908. The Main River water has a very high organic content and is very turbid. Good results were reported.[55] [56]

In the Netherlands, pretreated Rhine River water is brought in by pipeline to recharge the dunes from which Amsterdam and The Hague draw their supplies. Other recharge systems in the Netherlands do not use pretreatment.[57]

Sewage spreading.—It is not always feasible to divert water from streams nor is excess rainfall always sufficient for use in recharge operations. The Los Angeles Flood Control District carried out extensive experiments of spreading sewage effluent at Whittier and Azusa in the San Gabriel Valley. The waste water was treated in trickling filter plants prior to spreading. These tests verify that there was no significant bacterial contamination below a depth of 7 to 10 feet, and there was also no significant pollution of ground water. Although there now is a sewerline which is available and provides a means for ocean disposal, local preference has chosen to continue the recharge operation.[58]

The cost of reclaiming sewage and recharging it underground has been estimated on a 50-year financing basis to range from $9.30 to $18 per acre-foot, depending on location and existing facilities.[59] This is cheap storage, for water in southern California may have a value of from $35 to $40 per acre-foot.

One form of spreading, spray irrigation, is utilized very successfully for the treatment and disposal of some sewage and industrial wastes.[60] Recharge rates of 0.53 feet per day at Seabrook, N.J., were successfully maintained. The polluted water becomes potable after filtering through the ground. In one season the water table was raised 22 feet. About 1 billion gallons of waste water per year from food processing operations are disposed of from one plant alone.[61]

Artificial ground water recharge by injection

Recharge by wells is almost always used to recharge a pressure aquifer confined between an impervious stratum at the top and bottom. Because water of low turbidity and silt content is required and because of the cost per unit of water injected as compared to that of basin spreading, recharge by wells should only be used where spreading cannot be employed.[62]

Recharge to prevent sea water intrusion.—An effort to prevent sea water intrusion into an artesian aquifer has been undertaken at Manhattan Beach, Calif.[63] Treated Colorado River water was injected into nine 12-inch-diameter wells spaced at 500 feet intervals by applying heads of

[51] Henkel, K., "Slope Protection of Basins for Artificial Ground Water Recharge," Gas-u-Wasserfach, *93*, 10, 297 (1952).

[52] Buchan, op. cit., p. 114.

[53] Larson, T. E., et al., "Recharge of Ground Water at Peoria, Ill.;" Sewage, Water Works, *104*, 11, 488 (November 1957).

[54] Jansa, O. V. E., "Artificial Ground Water Supplies of Sweden," Intl. Union Geodesy, Geophysics, *2*, 227–231, Brussels (1951).

[55] Dechant, S., "Ground Water Recharge by the City Water Works at Bamberg," Gas-u-Wasserfach, *79*, 3, 36–39 (1936).

[56] Scheelhaase, F., Fair, G.P.M., "Producing Artificial Ground Water at Frankfurt, Germany," Engr. New Record, *93*, 5, 174–176 (1924).

[57] Buchan, S., Key, A., "Pollution of Ground Water in Europe," Bull. World Health Org. *14*, 563 (1956).

[58] "Study of Waste Water Reclamation and Utilization," Calif. State Water Pollution Control Board, Pub. No. 18, Sacramento (1957).

[59] Hodger, H. E., "Los Angeles Considers Reclaiming Sewage to Recharge Ground Basins," Civil Engr., *20*, 5, 323 (1950).

[60] Mather, J. R., "The Disposal of Industrial Effluent by Woods Irrigation," Trans. A.G.U., *34*, 2, 227–239 (1953).

[61] Remsah, I., "Hydrologic Studies at Seabrook, N.J.," doct. dissert., Columbia Univ., New York City (1954).

[62] Bauman, P., "Basin Recharge," Trans. ASCE, *122*, 466 (1957).

[63] Laverty, F. B., "Recharging Wells Installed to Stem Sea Water Intrusion," Wtr. Wks. Engr., 105, 871 (1952).

40 to 50 feet to the wells. The tests indicated that gravel jacketed wells with seals at the upper clay stratum were far superior to simple casing wells. It was found also that chlorination was essential to prevent clogging of the pores by otherwise harmless organisms. A total rate of 4.5 cubic feet per second of treated water was sustained with moderate heads.[64] An adequate water supply is required to maintain a continuous barrier.[65]

To reduce sea water encroachment on Long Island, owners who pump in excess of 69.4 gallons per minute from new wells for cooling and air conditioning must return the used water in an uncontaminated condition into the ground.[66] More than 1,100 recharge wells have been drilled on Long Island, N.Y., since 1933. Experience shows that gravel filters between an inner and outer casing are most satisfactory. Usual recharge rates are from 0.2 to 0.5 cubic foot per second.[67] Some of the recharge wells have been in service over 20 years, with maintenance work required during the period.

Temperatures of recharged water may range from 2° to 20° F. higher than the water pumped from the ground. This has caused a serious increase in temperature of ground water only in the vicinity of centers of considerable recharge.[68] Increase in temperature of ground water is observed when cooling water is recharged by wells in Sacramento, Calif. Some well water temperatures have risen as much as 20° F.[69]

Brackish water wells have been recharged with fresh water in El Paso, Tex., Camp Peary, Va., and Brooklyn, N.Y. There appears to be little intermixture of the fresh and saline waters, and aquifers containing highly mineralized waters can be made useful for storage of fresh water.[70–73]

Recharge during offpeak season.—To stop a serious decline in the water levels at Louisville, Ky., 1.7 million gallons per day of cold city water were recharged through several supply wells during the spring of 1944. This recharge plus natural recharge gave an ample supply of cold water during summer months when city water was too warm for use in plants.[74]

A test to determine the feasibility of storing water in natural underground reservoirs to supply city peak demand was conducted at Amarillo, Tex. Water was injected during winter months at about 1,000 gallons per minute, and due to slow lateral movement 80 percent could be recovered by pumping during the remainder of the year.[75]

Recharge using surface water.—An investigation into the fundamental principles of applied recharge of ground water reservoirs in alluvial deposits was made in the Grand Prairie region of Arkansas. It was found that air entrainment was the most serious cause of plugging.[76] Diffusion wells have been used successfully in Long Island, N.Y., in unconsolidated sand and gravel. The diffusion wells consist of prefabricated, reinforced concrete pipe sections with flared openings in the barrels. One type of pipe section is 7.5 feet in diameter and 4 feet in length, the other is 10 feet in diameter and 6 feet in length. The larger section has 7-inch walls for depths reaching 60 feet and 10-inch walls for greater depths. The wells are sunk by the open caisson method. Rates of 440 gallons per square foot of seepage area per day are indicated. Catch basins with open bottoms permit heavy silt to settle out before storm water enters the diffusion well.[77] Recharge wells extending into limestone formation of a creviced nature allow high disposal rates. At Orlando, Fla., wells penetrate from 120 to 1,000 feet, having casings to depths of 70 to 140 feet and capacities to 9,500 gallons per minute. Although considerable rubbish is carried into the wells, the cavernous limestone formation seldom becomes clogged.[78] Most States do not permit the

[64] Bauman, op. cit., p. 473.

[65] Bruington, A. E., "Progress on Barrier to Sea Water Intrusion," Proc. ASCE, No. 2159 (1959).

[66] Johnson, A. I., "Ground Water Recharge on Long Island," J. AWWA, 40 1159 (1948).

[67] Todd, D. K., "Ground Water Hydrology," p. 284, John Wiley, Sons, New York (1959).

[68] Brashears, M. L., Jr., "Artificial Recharge of Ground Water on Long Island, New York" Econ. Geol., 41, 5, 504 (1946).

[69] Jennings, J. C., "Disposal of Waste Cooling Water," J. AWWA, 42, 6, 578–582 (1950).

[70] Sundstrom, R. W., Hood, J. W., "Results of the Artificial Recharge of the Ground Water Reservoir at El Paso," Tex. Bd. Water Engr. Bull. 5206 (1952).

[71] Brashears, M. L., Jr., "Recharging Ground Water Reservoirs with Wells and Basins," Mining Engineering, *5*, 1029 (1953).

[72] Cederstrom, D. J., "Artificial Recharge of a Brackish Water Well," Commonwealth, 14, 31, Va. State Cham. Commerce (December 1947).

[73] Muegge, O. J., "Artificial Recharging of Water-Bearing Formations," J. AWWA, 50, 170 (February 1958).

[74] Guyton, W. F., "Artificial Recharge of Glacial Sand and Gravel with Filtered Water at Louisville, Kentucky," Econ. Geol., *41*, 664 (1946).

[75] Moulder, E. A., Frazor, D. R., "Artificial Recharge Experiments at McDonald Well Field, Amarillo, Texas," Tex. Bd. Water Engrs., Bull. 5701, 1 (January 1957).

[76] Sniegocki, R. T., "Plugging by Air Entrainment in Artificial Recharge Tests," given Natl. Water Well Assoc. meeting, Washington, D.C. (November 1958).

[77] Welsh, W. F., "Conservation of Water," Water, Sewage Works, 103, 10, 472 (October 1956).

[78] Banksley, A. G., Cooper, H. H., Jr., "Artificial Recharge of Artesian Limestone at Orlando, Fla.," Econ. Geol., 41, 293–307 (1946).

disposal of drainage and waste waters in formations of a creviced nature.

At Fresno, Calif., several hundred wells discharge storm runoff to a point at least 10 feet above the normal water table to prevent contamination of water supplies. A special filter system is built into the top of each well. The average recharge well capacity is about 0.2 cubic feet per second for a 24-hour period.[79]

Tests in California indicate that 0.4 to 2 cubic feet per second of water with 15 parts per million of chlorination may be injected continuously for a month or more before redevelopment, injection and treatment may total $15 to $25 per acre-foot, hence this method is useful only where the value of water is high or a secondary value is to be achieved.[80]

Direct recharge with sewage effluent.—It was found that sewage approximating the final effluent from secondary sewage treatment in terms of suspended solids, could be successfully injected underground through the experimental recharge well at a rate equal to one-half the safe yield of the well, and that the well could be developed to restore its original characteristics after clogging had progressed to any maximum limit consistent with safety to the installation. An injection rate (84 gallons per minute per foot) equal to the best reported for fresh water recharge was found to be practical.[81]

Experiments were conducted with injection of sewage effluent from a high rate activated sludge process at the Hyperion treatment plant at Los Angeles. Difficulties were experienced at first due to the inadequacy of perforations and underdevelopment of the well, too high a BOD content, too high a suspended solids concentration, and deposition of corrosive products in or near the perforations of the well. Encouraging results were obtained when the recharge well was rehabilitated by bailing, surging, and using effluent from the intermittent spreading method. The spreading basin provided filtration through 13 feet of windblown sand. The chlorination rate to the well was reduced from about 20 to 0.7 parts per million, thereby reducing corrosion. A well has received continued injections for 127 days with a head not exceeding 46 feet. During this test the biochemical oxygen demand and suspended solids of the injected water averaged 1.5 and 13 parts per million, respectively. Chlorination to a residual has been effective in maintaining a water which meets U.S. Public Health Service drinking water standards for coliform bacteria.[82]

Plans to use effluents from Hyperion for the operation of the west basin barrier in Los Angeles County are being considered, but it is stressed that the effluent would require additional treatment by passage through relatively large natural sand filters or rapid sand filters to remove suspended solids and lower the biochemical oxygen demand.[83]

Protection of ground water

Ground water can be developed whereby the aquifer remains productive over a long time. To accomplish this the water must not be mined excessively and the ground water must not become polluted.

Controlled withdrawal.—Limited withdrawal schemes are currently being tested in several areas of the Nation. Generally most of the conservation practices are associated with those basins where water is mined, as differentiated from those basins which depend on annual recharge. Long Island is an area where water is replenished with surface recharge and where there is a use restriction.

Arizona has a basin-use restriction law. In some places water can be used for industry but not for irrigation.

New Mexico has the power to close basins to further developments and indirectly define the well spacings. The State engineer of New Mexico currently exercises control over nine declared underground basins. The law states:

> Beneficial use is the basis, measure, and limit of the right to the use of water. Priority in time of appropriation shall give the better right.[84]

In the high plains area of Texas conservation is not so well defined. Legislative enactment has authorized the formation of "underground water

[79] Hallsten, J., "Wells for Drains," The Highway Mag., 46, 212-213 (1955).
[80] Laverty, F. B., "Ground Water Recharge," J. AWWA, 44, 677-681 (August 1952).
[81] Krone, R. B., McGurdy, P. H., Gotaas, H. B., "Direct Recharge of Ground Water with Sewage Effluents," Proc. ASCE, 83, SA1335 (August 1957).
[82] Van der Hoot, H. A., "Water Reclamation at Hyperion," J. Sew. Ind. Wastes, 29, 10, 1143-1144 (October 1957).
[83] Anon., "Los Angeles Looks Further into Well Recharge," Engr. News Rec., 158, 18 (1957).
[84] Bliss, J. H., Manual of Rules and Regulations Governing the Drilling of Wells and the Appropriation and Use of Underground Waters in Declared Basins of the State of New Mexico, State Engineer's Office (1951).

conservation districts." These districts may be created over an entire underground water reservoir or a subdivision of an underground reservoir. The districts are autonomous, but cannot elect their five-member board until the State board of water engineers has defined the underground reservoir or subdivision thereof. Although the district once formed by an election has considerable power of rulemaking, the legislature did not specifically authorize such districts to adopt proration rules to limit the rate or quantity of production of water except to prevent waste. Opinions vary as to whether the districts can prescribe and enforce proration in a manner similar to the Railroad Commission's authority in oil and gas production. In Water District No. 1 a well-spacing program based on flow was adopted,[85] but two of the major producing counties within the bounds of the district have not seen the need for joining the district.

There is little precedent in the acts of the eastern part of the United States for the regulation and use of water approaching the scale of water regulation in the Western States. There is no extensive legislation controlling ground water in foreign countries, although considerable interest is being expressed in areas such as Australia and South Africa.

Pollution prevention.—In 1957, 33 States reported some contamination of ground water by sewage and trade wastes, respectively.[86]

It has been reported that when individual wells and sewage systems are placed on relatively small plots it may be anticipated with some certainty that synthetic detergents will appear in the well. In appropriate formations the average homeowner may contribute 100 pounds of synthetic detergents to the ground water each year.[87]

In general, chemical pollutants, because of their greater travel distance, are much more serious than bacterial contaminants.[88] [89]

One of the greatest causes of pollution in European ground waters is saline intrusion which is usually caused by overpumping. Several countries have had ground-water contamination by heavy rainfall and infiltration of contaminated surface water. Also, there have been reports of sewage contamination being caused by leaking sewers and improper sewage-disposal methods. The United Kingdom, Switzerland, Portugal, Sweden, and Spain have reported industrial or trade wastes as a source of ground-water contamination.[90–93]

Location and evaluation of ground water

The surface reconnaissance technique which seems best suited to the problem of exploration involves measuring the electrical resistivity of the subsurface strata. Variations in resistivity are dependent on the type of rock, degree of saturation, and the mineral content of the water present. Experience and research have enabled these variations to be interpreted in such terms as geologic structure, rock type and porosity, water content and water quality.[94] Analysis of resistivity data must be interpreted in the light of the geology of the area as far as it is known, or can be summarized from visual examination. Based on resistivity surveys, successful wells have been drilled in the Middle East in 75 to 90 percent of all cases.[95]

Resistivity surveys in increasing numbers have been reported in the United States. These have been used to locate ground-water level, obtain relative salinity and outline promising aquifers. Test drilling has proved the correctness of resistivity in a reported 92 percent of the cases.[96]

Seismic refraction and reflection.—Seismic methods involve the detonation of small charge, and recording the travel time for the resulting direct and reflected sound or shock waves to reach instruments located at known distances from the explosion. Since the speed of the wave is different in different rocks this method can be used to locate

[85] Rules of the High Plains Water Conservation District No. 1 (Texas) Rule No. 8 as Amended (Feb. 4, 1957).

[86] Task Group Report, "Underground Waste Disposal and Control," J. AWWA, 49, 1336 (October 1957).

[87] Flynn, J. M., et al., "Study of Synthetic Detergents in Ground Water," J. AWWA, 50, 1551–1562 (December 1958).

[88] Gotaas, H., "Report on the Investigation of Travel of Pollution," 218 pp., State Water Pollution Control Board, State of California Pub. No. 11 (1954).

[89] Stiles, C. W., Crohurst, H. R., "The Principles Underlying the Movement of *B. coli* in Ground Water with the Resultant Pollution of Wells," Pub. Health Report 38, 1350 (June 1953).

[90] Buchan, S., Key, A., "Pollution of Ground Water in Europe," Bull. WHO, 14, 949–1006 (1956).

[91] Ullerstam, A., "The Adverse Influence of any Type of Organic Matter on the Quality of Under Ground Water and Ways and Means of Controlling Such Risks in Sweden," Condensed in J. AWWA, 49, No. 5 (May 1957).

[92] Key, A., "The Recharge of Ground Water—Problems and Dangers," J. Sci. Food and Agriculture, 8, 605 (1957).

[93] Thiem, G., "Groundwater, River Water, Sewage and Their Relationship," Gesundh. Ing., 76, 276 (1955).

[94] Todd, D. K., "Investigating Ground Water by Applied Geophysics," Proc. ASCE, 81, Jan.-Feb. 625-2 (1955).

[95] Paver, G. L., "The Geophysical Investigation of Underground Water Supplies: A Geological Analysis of Observed Resistivity Data," J. Instn. of Water Engrs., 4, 237–266 (May 1959).

[96] Todd, op. cit., pp. 625-2.

subsurface formations. Wave motion is higher in moist than in dry formations but the actual presence of ground water is difficult to determine since the velocities from saturated and unsaturated zones frequently overlap. It has been used extensively in New England to locate ground water supplies.[97]

Well logging methods.—This method is used to measure changes in properties by means of instruments lowered into a well to obtain information on the geologic strata intersected by the well. Instruments may be used to measure resistivity, gamma ray and neutron radiation, temperature, bore-hole diameter, velocity and direction of flow within a well and conductivity of the bore-hole fluid.

Numerous water-well logging operations have been reported. It is estimated that 50 percent of the rotary-drilled wells in the San Joaquin Valley in California are electrically logged. Logs have been found beneficial for determining formation types, for locating aquifers, ground-water contaminants, stray earth currents which may produce electrolysis and corrosion, for proper placement of perforations, and for correlating formations from well to well.[98]

Cost.—The cost of adequate electric logging may run to about half the average cost of domestic wells. The costs are not serious where deposits of large volume occur at rather shallow depths, nor are they serious for obtaining accurate information on a large aquifer serving a concentrated demand. Surface techniques may be of most assistance for locating small domestic wells because they are lowest in cost.[99]

4. SURFACE WATER CONSERVATION

Estimates indicate that the total daily average of all uses (i.e., irrigation, rural, public water supplies, industrial, and electric steam power) will grow to 453.08 billion gallons in 1975.[1]

Natural surface supplies in rivers and streams come at the wrong time, and they are not necessarily of the desired quality. The flow may occur where there is little need for the water.[2]

Improved yields

Generally, control over water yield can be exercised by three kinds of activities.[3] The most basic means of controlling soil moisture, runoff, and percolating waters is through some means of weather modification.

Weather modification

Rainmaking and the control of rainfall intensities has been an intriguing concept for generations. The interest in the artificial precipitation of moisture from the atmosphere by use of dry ice, silver iodide smoke and water sprays is partially due to the fact that there are tremendous quantities of water available in this mobile reservoir. It has been estimated that three-fourths of the moist air masses moving eastward from the Pacific Ocean reach the east coast.[4] There is a water balance on the North American Continent of 91 centimeters atmospheric moisture entering, 76 centimeters leaving, and 15 centimeters liquid runoff. From the runoff fraction and in connection with the extensive recirculation patterns over the continent, it is quite possible that reprecipitation from the same air masses is possible. Furthermore, the overhead moisture remaining in the atmosphere even after a storm is probably about 99.5 percent of the original moisture content. At a value of $20 per acre-foot this moisture would be equivalent to about $2,000 per square mile for agricultural purposes.[5]

According to the conclusions and recommendations prepared by the Advisory Committee on Weather Control, as released in January 1958, measurements made in 386 seeded storms showed increases of 14 percent in the orographic and semiorographic areas and no particular increase in the nonorographic regions.[6 7]

The areas most favorable for artificial cloud seeding in the western portion of the country are Arizona, California, Colorado, Idaho, Montana,

[97] Lincham, D., Keith, S., "Seismic Reconnaissance for Ground Water Development," J. New Eng. Water Works Assn., 63, 76–95 (1949).

[98] Todd, op. cit., papers 625–629.

[99] Ackerman, Lof, op. cit., pp. 404–405.

[1] Picton, W. L., "Water Use in U.S. 1900–1957," Business and Defense Services Administration, U.S. Dept. of Commerce (January 1956).

[2] Ackerman, E. A., Lof, G. O., "Technology in American Water Development," p. 79, The Johns Hopkins Press, Baltimore (1959).

[3] Colman, E. A., "Vegetation and Watershed Management," p. 8, Ronald Press Co., New York (1953).

[4] Benton, G. S., Estaque, N. A., Dominitz, J., "Scientific Report No. 1," Johns Hopkins Univ., Geophysical Research Div., Air Force Cambridge Research Ctr. (1949).

[5] Krick, I. P., "Rain Increase Projects in Relation to Water Resources," Water and Sewage Works, 99, 260–261 (July 1952).

[6] Berndt, G. D., "An Evaluation of Commercial Cloud Seeding Operations Conducted During Summer Months in South Dakota," Adv. Comm. Weather Control Tech. Report No. 5 (1957).

[7] Thom, H. C. S., "An Evaluation of a Series of Orographic Cloud Seeding Operations—A Statistical Method of Evaluating Augmentation of Precipitation by Cloud Seeding," Adv. Comm. Weather Control Final Report, 2, 25–49, 524 (1958).

Nevada, New Mexico, Oregon, Utah, Washington and Wyoming. Of these California, Oregon, and Washington could possibly obtain more than 3 million acre-feet of additional water annually. Idaho and Colorado could obtain about 2 million acre-feet, respectively.[8-10]

Impoundments and surface modifications

As of 1954 there were about 1,330 reservoirs and natural lakes in the United States with a capacity of 5,000 acre-feet or more. This represents a storage of about 90 billion gallons of water, but it is equivalent to only about 2 hours of average runoff. Also, half of this storage is concentrated in 21 reservoirs.[11]

Flood control.—Approximately $600 million has been spent annually for the operation of flood control devices. If floods continue to occur the average annual flood damage will reach an estimated $700 million.[12] Studies now show that flood occurrence with its economic implications for property damage and agricultural loss is growing more rapidly than our progress in meeting the problem.[13] Furthermore, flood control and channel straightening sometimes lead to unpredicted and costly difficulties. As a result of making sections of the Rhine River a confined-straight channel there is now a progressive lowering of the riverbed. This same effect is apparent below Lake Mead on the Colorado.

As an example of flood storage or flood-control storage, there are 11 major reservoirs in the Red, Trinity, Brazos, Colorado and Rio Grande Rivers. The total capacity of these 11 reservoirs is 19 million acre-feet, of which 11 million are allocated for flood-control storage. All of these reservoirs with the possible exception of three have discharged floodwaters in uncontrolled flows.[14]

Sediment control.—The quality of the water is definitely related to the sediment load of the stream. The silt suspended in the Brazos River during an average year would cover an area of more than 20,000 acres with an average thickness of about 1 foot.[15] This shows the high rate at which silt is being discharged to the Gulf of Mexico. The silt load into the Possum Kingdom Lake on the Brazos results in about 6,000 acre-feet of sediment deposited annually.

The earliest measurements of sediment in a stream were made on the Rhone River in France in 1808, and on the Mississippi River in the United States in 1838. One of the longest records of sediment movement is that involving the Rio Grande which was started in 1894. The Geological Survey now operates 170 such stations in the United States.[16] As an example of the cost of this sediment control, $100 million is needed to pay for sediment storage in three of the great reservoirs on the Missouri River.[17]

Evaporation control.—A study by the U.S. Geological Survey estimates that in 17 Western States more than 21 million acre-feet of water are evaporated annually from the surfaces of fresh-water streams, lakes, canals, ponds, and reservoirs.[18] Of this total about 13 million acre-feet are lost from large lakes of more than 500 acres. Approximately 3.3 million acre-feet of water are evaporated from small reservoirs and streams while the remaining losses are from principal rivers. The largest amount of evaporation in big lakes occurs in California. However, the largest total amount of evaporation, about 2.2 million acre-feet annually, occurs in Texas. This represents about 20 times the total reclaimable waste water available in the State of Texas during 1954.

Storage capacity equal to a year's flow may regulate 30 percent of the flow; however, doubling the capacity may only increase the regulation by a third. As an example, present storage in the Colorado River is 29 million acre-feet. If 50 million acre-feet of proposed storage were constructed, the net advantages would probably be offset by increased evaporation losses.[19] It must

[8] Ackerman, E. A., Lof, G. O. G., "Technology in American Water Development," p. 375, The Johns Hopkins Press, Baltimore (1959).

[9] Krick, I. P., "Technical and Economic Aspects of Weather Modification in Relation to Water Supply," J. Instn. Water Engrs., 8, 4, 336 (July 1954).

[10] Spanski, R. F., "Geophysical Techniques in Location of New Sources of Water," J. AWWA, 50, 185-192 (February 1958).

[11] Thomas, N. O., Harbeck, G. E., Jr., "Reservoirs in the U.S.," U.S. Geol. Survey Water Supply Paper No. 1360-A (1956).

[12] Page, C., "Planning for Conservation and Development of Water Resources," presented ASCE Natl. Conv., Washington, D.C. (October 1959).

[13] White, G. F., et al., "Research Paper No. 7," Dept. of Geography, Univ. Chicago.

[14] Texas Floods, April-June 1957, State Board of Water Engineers, Austin, Tex.

[15] Bloodgood, D. W., "A Report on Silt Studies of Texas Streams," State Board of Water Engineers, Austin, Tex. (1952).

[16] Langbein, W. B., Hoyt, W. G., "Water Facts for the Nation's Future," p. 32, The Ronald Press, New York (1959).

[17] Brune, G. M., "Sediment Is Your Problem," SCS AIB 174, USDA, Government Printing Office, Washington, D.C. (1958).

[18] Myers, J. S., "Water Evaporation Losses in Western United States," Water and Sewage Works Abs. (June 1959).

[19] Langbein, W. B., "Water Yield and Reservoir Storage in the United States," USGS Cir. No. 409 (1959).

be remembered that the gross annual loss of water through evaporation might average 7 feet, mounting as high as 10 feet per year under severe drought conditions.

The complexities of the many-sided surface water conservation program are further exemplified by the large number of soil-conservation farm ponds now collecting water. It is estimated that the number of farm and ranch ponds constructed under the direction of the Soil Conservation Service program now number 90,000. On the upper Brazos River watershed in Texas the number of ponds of all types in 1953 was 18,000 as compared to 342 in 1943. This number is expected to increase to 26,000.

Data show that under climatic and soil conditions prevailing in west Texas the runoff from individual tracts of land may be reduced from 30 to 100 percent during normal rainfall years.[20] It would appear that the runoff from lands under complete conservation treatment will be relatively light in west Texas and other similar areas during years of normal or less than normal rainfall. It is probable then that the future municipal supplies must depend largely on the runoff from rough and poor soil or terrain incapable of economic conservation treatment, and from ranchlands incapable of good grass covers, and from water stored during an occasional wet year.[21]

The number of stock tanks and conservation tanks has now reached such proportions that it offers competition with other diversions for water use. The soil conservation practices and land use to date, exclusive of stock tanks, have not materially changed the historic flow in the Brazos River Basin, due largely to the application of conservation practices to a relatively small percentage of the watershed, and also to balancing effects of the practices both decreasing and increasing runoff.[22]

Soil conservation practices, other than tanks, include contour plowing, terracing, clearing, and other similar practices. During the 10 years 1943–53, stock tanks diverted an estimated average of 35,000 acre-feet per year from Possum Kingdom Reservoir. This is about 4.3 percent of the average flow.

The most likely means of controlling evaporation losses, other than selecting the reservoir sites and tank sites with a minimum exposure of surface area, is to reduce the vaporization rate. Certain organic chemicals containing a long hydrocarbon chain terminating in an alcohol group, acid group, or some other radical compatible with water will form an invisible, insoluble film on the water surface. A cover is thereby created which can prevent vaporization of water. Such a material is cetyl alcohol (hexadecanol).[23–26] Small hard lumps of this material not over 2 mm. in diameter are believed to be the most desirable. The best evaporation retardants have shown savings of evaporation as high as 93 percent for short periods of time and 45 percent for as long as 15 days in the laboratory. However, this efficiency cannot be maintained in the field. No deleterious or toxic effects on fish, plankton, animals, or human beings have been observed.[27] Biological destruction of hexadecanol monolayers is large enough so that it should be considered economically.[28]

Watershed control

Watershed protection and soil-water conservation are inseparable. Well conceived soil, range, and forest management programs have marked effects upon the runoff characteristics of a river basin.

Range and forest management.—Control experiments have verified repeatedly the fact that streamflow is regulated by forests.[29 30]

Grazing management is one of the most successful means of improving rangeland watersheds. Also, mechanical land treatments for brush con-

[20] Dickson, R. E., et al., "Level Terraces—No Runoff in Twelve Years," Soil Conservation 4, 11 (May 1939).

[21] Freese, S. W., "General Effect of Soil Conservation Work on Stream Flow in West Texas," Tex. Sec. ASCE, Houston, Tex. (October 1954).

[22] Carothers, H. P., Newnam, F. H., Jr., "Effect of Soil Conservation Practices on Runoff in the Brazos River Basin," Tex. Sect. ASCE, Fall meeting, Austin, Tex. (1956).

[23] Harbeck, E. G., Koberg, G. E., "A Method of Evaluating the Effect of a Monomolecular Film in Suppressing Reservoir Evaporation," J. Geophys. Res. 64, 1 (January 1959).

[24] Beadle, B. W., Cruse, R. R., "Water Conservation Through Control of Evaporation," J. AWWA, 49, 397–402 (April 1957).

[25] Dressler, R. G., Johanson, A. G., "Water Reservoir Evaporation Control," Chem. Engr. Progress, 54, 1, 66–69 (1958).

[26] Downing, A. L., Melbourne, K. V., "Chemical Conservation of Water," J. Instn. Water Engrs., 11, 5, 438–442 (August 1957).

[27] Ackerman. E. A., Lof, G. O. G., "Technology in American Water Development," p. 456, The Johns Hopkins Press, Baltimore (1959).

[28] Ludsack, F. J., Ettinger, N. B., "Biological Oxidation of Hexadecanol," J. AWWA, 49, 849–858 (July 1957).

[29] Bethlahmy, N., "Forests and Water Yield," ASCE Proc., San. Engr. Div., 84, Sep. No. 1848 (November 1958).

[30] Rich, L. R., "Consumptive Use of Water by Forest and Range Vegetation," ASCE Proc., 77, Sep. No. 90 (October 1951).

trol by root ploughing, discing, and range reseeding are beneficial.[31]

The damage done by fire to the soil, ensuing works on the river, and quality of the water outweighs any temporary improvements that may result from burning.[32-34]

The best water quality protection and flow-regulation possibly can be obtained through forest cover. This deep-rooted type of cover uses less water, is more easily maintained and provides additional income. In New England it apparently does not matter whether the forest cover is hardwood or conifer.[35]

In 11 Western States much public range and forest land remain because an inadequate water supply has restricted the distribution of population centers. Possibly the greatest public benefit of these areas, despite the special interests of grazers, is for their watershed value and not for grazing, timber, wildlife, and recreation.[36]

Soil conservation practices.—Some aspects of soil conservation protection involve establishment of vegetation cover and farm ponds. The latter may have a considerable effect upon downstream flows during dry periods and is discussed under the subheading "Evaporation Control."

Drainage.—Drainage is another conservation measure. Paradoxically, on many occasions it is a costly and wasteful practice. As an example, from 1934–54 approximately 1 million acres in the Dakota and Minnesota pothole areas have been drained, with another 1.5 million acres in process.[37]

In the eastern counties of South Dakota, where much of the drainage was done with Federal encouragement and public money, requests were made later for drought relief.[38]

At the same time that the pothole areas were being drained and eliminated as waterfowl nesting areas, another arm of the Government initiated a costly soil bank program, subsidized the construction of thousands of farm ponds, and bought wildlife refuge and management areas.

Recreation.—Water development projects have created one of the most important recreational resources in the United States. It has been estimated that public use of reservoirs under the Corps of Engineers direction grew to almost 95 million visitor days; this is an increase of almost 20-fold in 10 years.[39] To many people, weekend recreational value is more apparent than flood damage control.

With respect to recreation, it has traditionally been the practice of municipalities to restrict some or all forms of recreation on watersheds and reservoirs used to supply water for domestic consumption. In the New England area, specifically Massachusetts, about 26 percent of the pond area of the State has been set aside for water supply purposes. It is quite apparent that the restrictive uses of watersheds and lakes in the populated East are much more severe than in the West. However, reasonable protection of water supplies based on public health justifications could possibly be reviewed in the light of modern treatment capabilities.[40 41]

Streambank vegetation.—Evapo-transpiration losses are reaching excessive proportions. There are in excess of 17 million acres of phreatophytic vegetation (plants tapping the water table or the capillary fringe) in the 17 Western States.

In New Mexico alone, the salt cedar, 1 of the 80 different species of phreatophytics, occupies 440,000 acres. The total water lost by evapotranspiration each year in this area is about 25 million acre-feet.[42 43] This represents about 75 percent of the total storage of Lake Mead or about 3.5 times as much as the average annual runoff of the Rio Grande River.

[31] Merrill, L. P., "Relationship between the Watershed Management—on Rangeland, Land Productivity and the Environment," Private communication, Texas Agric. Experiment Station, Sonora, Tex. (1959).

[32] Sinclair, J. D., Hamilton, E. L., "Stream Flow Reactions of a Fire-Damaged Watershed," Hydraulics Div., Meeting, ASCE (September 1954).

[33] "Influences of Deforestation and Erosion Control upon the Hydrology of the Pine Tree Branch Watershed, 1941–1950." TVA Tech. Monograph 86 (1955).

[34] Johnson, E. A., and Kovner, J. L., "Effect on Streamflow of Cutting a Forest," Forest Science, 2, 82–91 (1956).

[35] Lull, H. W., Tripp, N. R., "The Management of Forested Watersheds in New England," J. New Eng. WW, 72, 341–349 (December 1958).

[36] Cottam, Walter P., "The Role of Ecology in the Conservation of Renewable Resources," Proc. Amer. Conf. on Conservation of Renewable Natural Resources, Government Printing Office, 396–401 (1948).

[37] Schrader, Thomas A., "Water Fowl and the Pot-Holes of the North Central States," Year Book of Agriculture, Washington, D.C., pp. 596–604 (1955).

[38] Lynch, R. G., "Growing Water Problems," p. 61, Natural Wildlife Federation, Washington, D.C. (1959).

[39] Page, C., "Planning for Conservation in the Development of Water Resources," given ASCE Natl. Conv., Washington, D.C. (1959).

[40] Weston, A. D., "Protection of Watersheds, Sanitary—Are We Overdoing or Underdoing It?" J. New Eng., WW, 65, 256–285 (September 1951).

[41] Pummill, L. F., et al., "Pollution Control in South-Western Reservoirs and Watersheds," J. AWWA, 50, 789–799 (June 1958).

[42] Thompson, C. B., "Importance of Phreatophytes in Water Supply," ASCE Proc., Irrig. Drain, 84, No. IRI-1502, 1–17 (January 1957).

[43] Coleman, E. P. A., "Vegetation and Watershed Management," p. 340, The Ronald Press Co., New York (1953).

In the southern Appalachian region it has been found that important gains in water yield may be obtained by eliminating bank vegetation.[44]

There are several means by which the salt cedar might be controlled: (1) aerial and ground spraying with herbicides, (2) clearing, (3) discing, (4) mowing, (5) burning, (6) channelization, and (7) flooding. At present, channelization appears to be the most effective means of salvaging water in river channels and reservoir delta areas.

Surface water pollution prevention

Much can be learned from the practices of European river and pollution control programs. The British have just completed a 100-year river-pollution-prevention program.[45] Table 8 lists various regulatory agencies and conditions of the rivers for several European countries.[46] Particular mention is made of Germany. Through the use of river authorities in the Ruhr basin a series of large impounding or artificial lakes have been constructed to serve as dilution basins for settled sewage and industrial wastes. These reservoirs have the effect of providing natural self-purification and are also used for recreation, bathing, boating, and the development of water power. This is only one of the examples of stream pollution and water quality planning on river basin scale.[47]

River pollution generally occurs as a result of excessive use of a stream as a diluting medium for municipal, industrial and agricultural wastes; but man-made structures, such as impoundments, may also alter the quality of the water.[48–52]

Low-flow augmentation.—The use of water for waste dilution alone competes with other beneficial uses, and legal aspects of providing water for pollution abatement are complex.[53, 54]

[44] Dunford, E. G., Fletcher, P. W., "The Effect of Removal of Stream Bank Vegetation Upon Water Yields," Amer. Geophys. Union Trans., 28, 105–110 (February 1947).

[45] Barclay, W. G., "One Hundred Years of Prevention of River Pollution," J. Sew. Purif. Pt. 3, 276–288 (1958).

[46] Key, A., "Pollution of Surface Waters in Europe," W.H.O. Bulletin, 14, 845–945 (1956).

[47] Klein, L., "Aspects of River Pollution," p. 425, Academic Press, Inc., New York (1957).

[48] Kittrell, F. W., "Effects of Impoundments on Dissolved Oxygen Resources," J. Sew. Indus. Waste, 31, 1065 (September 1959).

[49] Ingols, R. S., "Effect of Impoundment on Downstream Water Quality, Catawba River, So. Caro.," J. AWWA, 51 42–46 (January 1959).

[50] Chase, E. S., Ferullo, A. F., "Oxygen Demand Exerted by Leaves Stored under Water," J. Eng WW., 71, 307 (December 1957).

[51] Cooley, P., Harris, S. L., "Prevention of Stratification in Reservoirs," J. Instn. Water Engrs., 8, 517 (November 1954).

[52] Fish, F. F., "Effect of Impoundment on Down Stream Water Quality, Roanoke River, North Carolina," J. AWWA, 51, 47–50 (January 1950).

[53] Hull, C. H. J., "Preliminary Report of an Investigation of Low-Flow Augmentation for Stream Pollution Abatement," Dept. San. Engr. Water Resources, Johns Hopkins Univ. (February 1958).

[54] Hull, C. H. J., "Bibliography on the Effects of Impoundments on Water Quality," Report No. 2, Low-Flow Augmentation Project, Dept. San. Engr. Water Res., Johns Hopkins Univ. (April 1959).

TABLE 6.[1]—*European authorities for dealing with surface pollution*

Country	Condition of rivers	Existence of general law	Responsibility for sewage treatment	Remarks
The Netherlands	Main rivers polluted, not deoxygenated; some canals and Lake Ijssel badly polluted.	No	Municipality	Movement toward regional "polder boards" modeled after German river associations.
Belgium	Mostly badly polluted	Yes; 1950	Bureau of Waste Purification.	Regulations still to be issued; will lay down standards, and these will relate to rivers, not to wastes. Right of appeal is to Minister of Health.
United Kingdom	Few rivers offensive, some estuaries highly polluted.	Yes; 1951	River boards	Consent of board is required before discharge of new effluents. Board may lay down standards of quality or quantity. It can make bylaws and take legal action. Right of appeal through Minister of Housing and Local Government.
Germany	All large rivers carry pollution, not deoxygenated, generally support fish. Industrial rivers such as Emscher severely polluted. Smaller streams deoxygenated.	Yes	Municipality or river association.	River associations—cooperation of all designated cities, districts, mines, and large industrial undertakings (water supply—maintenance of purity, drainage—all in accordance with uniform plan). All economic matters relating to water are supervised.
Italy	Some rivers badly polluted—all polluted to some extent, including offensive smells.	No	Municipality	Ministry of Agriculture and Public Works for fishing interests—municipality must grant new factory permission to dump waste.
Switzerland	Rivers generally good. Lakes highly fertilized.	do	Canton	Practice of pollution control varies widely.
Denmark	Rivers generally good. All support fish; some pollution in estuaries.	do	Municipality, industry	Ministry of Fisheries is closely concerned with conditions of rivers. No general authority exists.
Portugal	Large rivers polluted	Yes	Directors-General: Water Services, Waters and Forests, and Public Health.	Laws excessively rigorous and impossible to enforce. Triple leadership ineffective.
France	Some polluted; most support fish.	do	Communities	Laws outdated.
Yugoslavia	Many streams offensive	No	Institutes of Health	No generally recognized standards.
Sweden	Occasional pollution	Yes; 1940	Municipality	Water pollution control of Royal Board of Fisheries acts as a Central Government authority.

[1] Klein, L., "Aspects of River Pollution," p. 425, Academic Press, Inc., New York (1957).

River-treatment plants.—In highly industrialized areas and where the flows of the stream are relatively small it has been recommended by some authorities that river-purification plants might be built at the side of the stream or even in the stream itself. The purpose of these plants is to increase the amount of dissolved oxygen in the water and accelerate the oxidation of the organic matter.[55] [56]

A relatively new technique for aerating rivers has been developed in Germany using turbines. This method has been used for several years on the Neckar River and will be adapted to the new power stations of the canalized Main River between Schweinfert and Hamburg.[57]

Influence of irrigation on water quality

In 1954, it was estimated that 26 million acres of land were irrigated involving a capital investment of $2 billion. Furthermore, 1.4 million acres were under irrigation in the humid areas of Arkansas, Louisiana, and Florida with an additional 0.3 million acres in the 31 Eastern States.[58] [59]

In Texas alone, as an example of a semiarid region, 3.7 million acres were under irrigation in 1950. This for Texas represents about 40 percent of the gross income from harvested lands. The water for irrigation in Texas is primarily good-quality ground water.

Salt concentration increases.—A striking example of water-quality deterioration is found on the Rio Grande. The average concentration of chlorides in the Rio Grande above El Paso, Tex., is about 48,000 tons per year. By the time the water has been used below El Paso there is a large decrease in flow above Fort Quitman. At this point the annual chloride concentration was about 159,000 tons, based on figures from the year 1949.[60]

Chemical concentration increases.—It has been estimated that approximately 12,000 tons of technical grade insecticides were applied to cotton in the six Eastern States during 1957.[61]

[55] Wilson, H. H., "Final Treatment of Sewage Effluent," The River Boards Association Yearbook, 85-95, H.M.S.O., London (1954).

[56] Tyler, R. G., "Polluted Streams Cleared Up by Aeration," Civ. Engr., 16, 348 (1946).

[57] Fuchs, H., "Airing of River-Water by Turbines," Personal Communication (October 1959).

[58] Quackenbush, Tyler H., "Factors Influencing Irrigation in Humid Areas," ASCE Proc., 80, Sep. No. 462, 1-7 (February 1954).

[59] Boegli, Willis C., "Economic Effect of Irrigation in a Subhumid Area," ASCE Proc., 80 Sep. No. 398, 1-15 (February 1945).

[60] Howard, C. S., "Irrigation and Water Quality," Reclamation Era, 39, 1-4 (1953).

[61] Nicholson, H. P., "Insecticide Pollution of Water Resources," J. AWWA, 51, 981-986 (August 1959).

5. CONTROL AND RECLAMATION OF SALINE WATERS

Control measures involve the impoundment of certain saline springs, impoundment of waters originating from basins which have predominant soluble salt outcrops, construction of salt water barriers in major rivers, and recharge of underground water formations or regulation of withdrawal.

Impoundment of saline springs

One attempt to control underground springs was made by the Bureau of Reclamation at Malaga Bend in New Mexico on the Pecos River. The mineralized water is being pumped to an off-stream reservoir that is isolated and self-contained.[1] In another case a joint study by Kansas agencies and U.S. Geological Survey of the Ninnescah River indicated possible improvement by building a relatively short underground dam to impound the mineralized water.[2] The USGS has also evaluated the geological factors which contribute to mineralization of the water in the Powder River.[3]

Salt barriers

There are two types of barriers usually considered for the control of salt water. In the case of surface water it is occasionally desirable to erect a barrier near the mouth of the river so that a greater portion of the streamflow, particularly low flows, can be utilized by the downstream user. The other type of barrier is the underground development which utilizes fresh water to build a ridge between the intruding salt water and the available fresh water.[4] As yet there are no fresh-salt water barriers on any of the major streams in the United States.

The principle of erecting a fresh water barrier is rather simple. Since the fresh and salt waters are frequently in the same or communicating formations the fresh water, being less dense, overrides the denser saline water. The two waters

[1] Hale, W. E., et al., "Possible Improvement of Quality of Water of the Pecos River by Diversion of Brine," Report of Pecos River Commission (1954).

[2] Metzler, D. F., "Arkansas-Red River Quality—Discussions," J. AWWA, 50, 1171 (September 1958).

[3] Swenson, H. A., "Geochemical Relationships of Water in the Powder River Basin, Wyoming and Montana," Trans. Am. Geophys. Union, 34, 443 (1953).

[4] Laverty, F. B., van der Goot, H. A., "Development of a Fresh Water Barrier in Southern California for the Prevention of Sea Water Intrusion," J. AWWA, 47, 886-908 (September 1955).

do not commingle. This phenomenon has been termed the Ghyben-Herzerg principle.[5]

Saline waters in petroleum recovery

In the production of oil there is always some sort of water produced. The amount of saline water usually increases as the oil production falls off. Sometimes the amount may be so large that it restricts the economic limits of oil recovery. As an example, about 3 billion barrels of oil were produced in 1956 and possibly at least 6 billion barrels of salt water.[6] This estimated quantity of brine represents 800,000 acre-feet. If it were distributed evenly it would provide every person in the United States with about 100 cubic feet of brine. In Texas alone, based on 1958 reports, the total salt water production in the east Texas field was 553,807 barrels on a "producing day basis."

In the early days, and also to some extent today, salt water was simply separated from the oil and allowed to flow by natural discharge into the streams. As an example, the Little River in Oklahoma contributes 5.1 percent of the flow to the Canadian but 40.4 percent of the total dissolved solids. This is primarily the result of oil production.[7]

A more sophisticated method of disposing of salt water is to put it under the ground. This is done by injecting it into some permeable, porous formation which will accept the injected brine. One important form of subsurface disposal is water flooding, in which the produced salt water is reinjected into the formation from which it came. It has been estimated that salt water injected into the Woodbine sand formation, an important east Texas oil-producing sand, reached a cumulative total of about 2.4 billion barrels in 1957. About 84 injection wells at that time were pumping about one-half million barrels per day.[8–12]

[5] Black, A. P., "Salt Water Encroachment—a Water Resource Problem," Water Works Engrg., 109, 338 (April 1956).

[6] Lewelling, H., Kaplan, M., "What to do About Salt Water," Atlantic Lectures, Univ. of Texas (1959).

[7] Krause, K. S., "Water Quality Studies in the Arkansas and Red River Basins," AWWA, 50, 1166–1170 (September 1958).

[8] "Salt Water Disposal—East Texas Field," 2d Edition, 1958. Petroleum Extension Service, Division of Extension, University of Texas (1958).

[9] "Water Quality Control for Subsurface Injection," Proceedings of a Short Course, Division of Extension, U. of Oklahoma, Norman, Okla. (Dec. 11–12, 1956).

[10] Bell, A. H., "Brine Disposal in Illinois Oil Fields," Illinois State Geological Survey, Circular 244 (1957).

[11] Wright, J., et al., "Analyses of Brines from Oil-Productive Formations in Oklahoma," U.S. Bureau of Mines, R.I., 5326 (1957).

[12] Jones, O. S., "Disposition of Oil Field Brines," U. of Kansas Publications (1945).

There are many interesting peculiarities of salt concentration in oilfield brines. It is not uncommon to find an oilfield brine which cannot be synthesized readily in the laboratory. There is a great deal of supersaturation which causes precipitation of some of the salts during injection operations.[13] There is no question that enforced salt water injection is a major step toward prevention of pollution in oil-producing areas.

Dilution of saline water with higher quality water

Although not common practice, it has been shown that various poor quality waters may be mixed with higher quality waters to produce a satisfactory supply for domestic, industrial, and agricultural uses. Some of the communities in the Midwest and West practice such procedures during periods of drought.

The Gulf Oil Co. at Port Arthur, Tex., mixes 1,600 parts of brackish water with 181 parts of fresh water by volume. The water is then demineralized by ion exchange.[14]

The notable example of water conservation in agriculture is that currently being practiced in Israel.[15 16]

Demineralization

Considerable progress has been made in increasing the efficiency of known desalting processes. Costs of these processes remain high. Some ways of lowering costs are to choose favorable types of water, location, power, byproduct recovery, and to establish highly selective uses of the finished product.[17]

Distillation by nonsolar heat resources.—One of the outstanding installations is that of Aruba in the Netherland Antilles, which produces 2.7 million gallons a day along with process steam and electric power at a cost of $1.75 per thousand gallons.[18–20] As a comparison, the maximum cost for municipal

[13] Greenwell, H. E., "Technology of Water Flood Corrosion," 14th Annual Conf. Natl. Assoc. Corrosion Engrs., San Francisco (March 1958).

[14] Resen, F. L., "How Gulf Purifies its Boiler Water," Oil Gas J., 55, 6, 106 (1957).

[15] Evenari, N., Koller, D., "Desert Agriculture: Problems and Results in Israel," "The Future of Arid Lands," p. 409, Amer. Assoc. Advt. of Science Washington, D.C. (1956).

[16] "Israel's Water Problem," Water Waste Engrg., 60, 436 (1956).

[17] "Saline Water Conservation for 1957," U.S. Dept. Interior, Washington, D.C. (January 1958).

[18] Howe, E. B., "Progress in Conversion of Saline Waters," J. AWWA, 50, 319–330 (February 1958).

[19] "Engineers Turn to Seas For A New Water Supply," Amer. Engrg. (June 1959).

[20] Powell, S. T., "Saline Water Conservation," Water Sew. Works, 106 (February 1959).

and irrigation waters in 1952, undistributed raw water, were 38 and 12 cents per thousand gallons.[21]

A large unit currently under construction is the multiflash sea water evaporation plant in Kuwait. It will be completed in 1960. At present 5 million gallons are being supplied but chemical conditioning precedes multieffect evaporators.[22] Existing plants are shown in table 7.

TABLE 7.—*Land-based sea water distillation plants* [1]

[Capacity in gallons per day]

Location:	
Aruba, Caribbean Sea	3, 500, 000
Buenos Aires, Argentina	150, 000
Curacao, Caribbean Sea	1, 000, 000
Dharan AFB, Arabia	200, 000
Ecuador	100, 000
Gibraltar	200, 000
Kindley AFB, Bermuda	225, 000
Kuwait, Persian Gulf	2, 500, 000
Las Piedras, Venezuela	450, 000
Mirafiori, Italy	300, 000
Nassau, Bahama Islands	1, 200, 000
Thule AFB, Greenland	130, 000
United States:	
Marcus Hook, Pa	300, 000
Morro Bay, Calif	150, 000
Los Angeles, Calif	100, 000

[1] Grupp, G. W., "The Conversion of Saline Water Becomes Necessary," Water and Sewage Works, 106, 287–290 (July 1959).

Solar distillations.—The costs of producing usable water by solar distillation are not proportional to the salt concentrations in the raw water.[23–24]

Processes utilizing membrane.—The electric membrane demineralization techniques using electrodialysis have considerable possibility. A plant has been constructed at Coalinga, Calif., to treat 28,000 gallons a day of brackish well water. The treatment costs of $1.10 per 1,000 gallons compare favorably with former rail transportation costs of $7.80 per 1,000 gallons.[25–27] Electrodialysis plants are listed in table 8.

Freezing processes.—Theoretically, freezing presents economies in salt water conversion because the latent heat of fusion of water is less than the latent heat of vaporization, resulting in decreased energy requirements as compared to distillation. Difficulty arises in the separation of pure ice crystals from the concentrating brines in the freezing mixture. It is reported that water can be produced with 500 parts per million salt from sea water at costs from about $1.00 per thousand gallons.[28]

TABLE 8.—*Electrodialysis conversion plants* [1] *existing or under construction* [2]

Location	Type of water treated	Capacity in gallons per day
Bahrein, Persian Gulf	Brackish	86, 400
Do	do	4, 800
Do	do	4, 800
Kuwait, Persian Gulf	do	4, 300
Libya, Africa	do	9, 600
Netherlands	Sea water	16, 000
Union of South Africa	Brackish	2, 400, 000
United States:		
Montana	do	16, 800
New York	do	12, 000
Texas	do	28, 000
Texas Tower No. 2	Sea water	2, 800
Texas Tower No. 3	do	2, 800

[1] Electrodialysis: Dialysis caused by electricity; electro-osmosis. Dialysis: Separation of crystalloids and colloids in sollution.
[2] Grupp, G. W., "The Conversion of Saline Water Becomes Necessary," Water and Sewage Works, 106, 287–290 (July 1959).

Solvent extraction.—This is a liquid-liquid extraction, using synthetic liquids to remove the water from the salt. The process is in the research phase.

Ion exchange.—In 1943, there were only four papers on this subject in a leading chemical engineering magazine. In 1953, there were 550. At least half of these papers dealt with water and waste water treatment.[29]

Economic boundaries.—One phase of desalinization not generally mentioned in the literature is that of salt disposal. In the case of sea water, 35,000 parts per million, this would amount to 146 tons of salt on a dry weight basis. In the case of brackish water, 4,000 parts per million only, 13 tons of salt are involved.

Desalinization of domestic and industrial waste waters is more economical when compared with desalting of sea water. Furthermore, a new waste problem is not created. As a comparison, the salt collected from demineralizing 800 million gallons per day of domestic waste would be 650 tons per day, based on 500 parts per million of salt. The salt from an equivalent amount of

[21] Annual Report, Office of Saline Water, p. 5, Dept. of Interior, Washington, D. C. (January 1959).
[22] Elliot, O. N., "Sea Water Purification," ASTM, STP No. 207, 25–40 (1956).
[23] Jong, T. de., "An Introduction to Solar Distillation," J. San. Engr. Div. Proc. ASCE, 84, No. 1704 (July 1958).
[24] UNESCO, "Utilization of Sea Water," Arid Zone Program No. IV, Reviews of Research on Problems of Utilization of Saline Water, p. 73 (1954).
[25] "Production of Freshwater by Ion Exchange Membranes Demineralization," Engineer, 204 (Sept. 6, 1957).
[26] Winger, A. G., et al., "Electrodialysis of Water Using a Multiple Membrane Cell," I.E.C., 47, 50–60 (January 1955).
[27] Krul, W. F. J. M., "Demineralization as an Additional Water Source for Arid Lands," The Future of Arid Lands, p. 272–278, Amer. Assoc. for the Advct. of Science, Washington, D.C. (1956).
[28] Saline Water Conversion Report for 1957, U.S. Dept. Interior, Washington, D.C. (January 1958).
[29] Lane, R. W., et al., "Hydrogen Exchange Resin For Steam Purity Testing," Ind. and Engr. Chem., 47, 47–50 (January 1955).

brackish water would be 3,900 tons per day, based on 3,000 parts per million of salt.

Acceptable water for low pressure boilers can be obtained easily for $133 per million gallons. To obtain an equivalent water from the ocean, 20,000 parts per million of salt in the effluent, would cost $780–$1,750 per million gallons.

The United States could well adopt some practices from other countries regarding water conservation. As an example, in Tunis the drinking water has a saline content of around 500 parts per million and the sewage has a salinity of about 1,500 parts per million. In this case it can be used directly for some forms of irrigation, but if two out of three gallons were treated and demineralized the sewage could be compared with the original water.[30]

A critical review of saline water conversation shows that it may be possible for a community of 1,000 to use a local saline ground source rather than an alternate surface source adjacent to the area. On the other hand, a city of 20,000 would do better to use a conventional source if it were available within 90 miles. For a population of 200,000 conversion would be uneconomical if the surface supply were within 300 miles. These calculations assume that a reservoir storage capacity of 1,000 days' firm draft is needed for a conventional supply.[31]

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